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The Class V Underground Injection Control Study

Volume 21

Aquifer Recharge and Aquifer Storage and Recovery Wells

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AQUIFER RECHARGE AND AQUIFER STORAGE AND RECOVERY WELLS

The U.S. Environmental Protection Agency (USEPA) conducted a study of Class V underground injection wells to develop background information the Agency can use to evaluate the risk that these wells pose to underground sources of drinking water (USDWs) and to determine whether additional federal regulation is warranted. The final report for this study, which is called the Class V Underground Injection Control (UIC) Study, consists of 23 volumes and five supporting appendices. Volume 1 provides an overview of the study methods, the USEPA UIC Program, and general findings. Volumes 2 through 23 present information summaries for each of the 23 categories of wells that were studied. This volume, which is Volume 21, covers two Class V well categories: aquifer recharge and aquifer storage and recovery (ASR) wells.

1. SUMMARY

Aquifer recharge and ASR wells are used to replenish water in an aquifer for subsequent use. While an aquifer recharge well is used only to replenish the water in an aquifer, ASR wells are used to achieve two objectives: (1) storing water in the ground; and (2) recovering the stored water (from the same well) for a beneficial use. Both of these types of wells, however, may have secondary objectives, such as subsidence control and prevention of salt water intrusion into fresh water aquifers. Aquifer recharge and ASR wells are found in areas of the U.S. that have high population density and proximity to intensive agriculture; dependence and increasing demand on ground water for drinking water and agriculture; and/or limited ground or surface water availability. ASR wells are also found in areas that have no freshwater drinking water supplies, or in coastal areas where salt water intrusion into freshwater aquifers is an issue.

Aquifer recharge and ASR well injectate consists of potable drinking water (from a drinking water plant), ground water (treated or untreated), and surface water (treated or untreated).[1] Water injected into aquifer recharge and ASR wells is typically treated to meet primary and secondary drinking water standards. This is done to protect the host aquifer and to ensure that the quality of the ground water to be recovered is adequate for subsequent use. In addition, most regulatory agencies require the injectate in aquifer recharge and ASR wells to meet drinking water standards in order to prevent degradation of ambient ground water quality. However, it should be noted that, in some instances, constituents have been measured at concentrations slightly above drinking water standards.

Aquifer recharge and ASR wells are drilled to various depths depending on the depth of the receiving aquifer. They may inject into confined, semi-confined, or unconfined aquifers, although most of these wells inject into semi-confined aquifers that have been partially dewatered due to overpumping.

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[1] Aquifer recharge and ASR well injecting only treated wastewater are addressed separately in the sewage treatment effluent well summary, which is Volume 7 of the Class V UIC Study.

No contamination incidents associated with the operation of aquifer recharge or ASR wells have been reported.

Because the major goal of aquifer recharge and ASR wells is to replenish water in aquifers for subsequent use and its injectate typically meets drinking water standards, aquifer recharge and ASR wells are unlikely to receive spills or illicit discharges.

According to the state and USEPA Regional survey conducted for this study, there are approximately 1,185 aquifer recharge and ASR wells documented in the U.S. This total includes 807 aquifer recharge wells, 130 ASR wells, and 248 wells (in California and Idaho) that cannot be distinguished among aquifer recharge and ASR wells in the available inventory. The estimated number of aquifer recharge and ASR wells in the nation is greater than 1,695, but unlikely to be higher than 2,000. This estimate does not include 200 wells proposed to be built in Florida as part of the "Everglades Restoration Project." Approximately 89 percent of the documented aquifer recharge and ASR wells are located in ten states: California (200), Colorado (9), Florida (<488), Idaho (48), Nevada (110), Oklahoma (44), Oregon (16), South Carolina (55), Texas (67), and Washington (12). Wisconsin has conditionally approved one ASR well as part of a pilot study at a municipal water system in Oak Creek, and a second pilot project in Green Bay, Wisconsin is under development. The project in Green Bay is expected to be operational within the next year.

The statutory and regulatory requirements differ significantly among the ten states where the majority of the aquifer recharge and ASR wells are believed to exist. In California and Colorado, USEPA Regions 9 and 8, respectively, directly implement the UIC program for Class V injection wells. However, both states have additional jurisdiction over aquifer recharge and ASR wells through state regional water quality control boards in California and permitting of extraction and use of waters artificially recharged in Colorado. The remaining eight states are UIC Primacy States for Class V wells. Oklahoma and Texas are UIC Primacy States that authorize aquifer recharge and ASR wells by rule, while Florida, Nevada, Oregon, South Carolina, and Washington require individual permits for the operation of aquifer recharge and ASR wells. In Idaho, construction and operation of shallow injection wells (<18 feet) is authorized by rule; construction and use of a deep injection well ($18 feet) requires an individual permit.

2. INTRODUCTION

Ground water is being increasingly used for agricultural, drinking, and industrial supplies in the United States. As a result, the available supply of fresh ground water is decreasing at an accelerated rate, and water managers and planners have been faced with the challenge of developing water management techniques to meet water demands (O'Hare et al., 1986; Pyne, 1995).

One technique that has been used in recent years is artificial aquifer recharge. Artificial recharge refers to the movement of water via man-made systems from the surface of the earth to underground water-bearing strata where it may be stored for future use (Griffis, 1976). Such recharge may be conducted for ground water resource management, water storage and recovery, prevention of salt water intrusion into fresh water aquifers, and subsidence control, among other purposes (Bouwer et al., 1990; Crook et al., 1991; Fairchild, 1985; Hamlin, 1987; North Carolina Division of Water Resources, 1996).

The advantages of aquifers over surface water impoundments as reservoirs for cyclic storage of water are: (1) permanence; (2) no loss of storage capacity due to sedimentation; (3) no loss of water due to evaporation; (4) less vulnerability to destruction and contamination; and (5) the absence of threat to downstream communities (by eliminating the possibility of dams breaking and floods occurring) (Kazmann, 1967).

Conventional methods of artificial recharge include surface spreading, infiltration pits and basins, and injection wells. Injection wells are the selected method of artificial recharge in areas where the existence of impermeable strata between the surface and the aquifer makes recharge by surface infiltration impractical or in areas where land for surface spreading is limited.

During the last 30 years, a special type of recharge well has been developed: ASR wells (Wilson, 1999; Pyne, 1995). What distinguishes an ASR well from an aquifer recharge well is its dual-purpose characteristic. While an aquifer recharge well is used only to replenish the water in an aquifer, ASR wells are used to achieve two objectives: (1) storing water in the ground; and (2) recovering the stored water (from the same well) for a beneficial use.

This summary addresses both aquifer recharge and ASR wells. These types of wells usually inject water into water supply aquifers. According to the existing UIC regulations in 40 CFR 146.5(e)(6), “recharge wells used to replenish the water in an aquifer” are considered Class V injection wells. ASR wells are considered Class V injection wells under the existing UIC regulations in 40 CFR Parts 144 and 146, but ASR wells are not specifically defined in the regulations.

Aquifer recharge and ASR wells that only inject reclaimed wastewaters are addressed separately in the sewage treatment effluent well summary, which is Volume 7 of the Class V UIC Study (the wells covered in this volume, Volume 21, do not inject sewage treatment effluent or inject such effluent mixed with ground water and/or surface water). Aquifer recharge wells used primarily for subsidence control or prevention of salt water intrusion into fresh water aquifers are addressed in Volumes 20 and 23 of the Class V UIC Study, respectively.

Connector wells, which create a direct connection, or bore hole, from one aquifer to another, are designed to drain surficial aquifers into a deeper aquifer and are used solely for dewatering purposes, not in a recharge capacity. Thus, connector wells are considered special drainage wells and are not included in this volume. For further information on connector wells, see the special drainage information summary, which is Volume 14 of the Class V UIC Study. Storm drainage wells, which may provide aquifer recharge while disposing of excess storm water, are addressed separately in Volume 3 of the Class V UIC Study.

3. PREVALENCE OF WELLS

The primary factors for locating aquifer recharge and ASR wells include: population density and proximity to intensive agriculture in a low moisture region; dependence and increasing demand on ground water for drinking water and agriculture; high seasonal fluctuations in water demand and availability; and limited ground or surface water availability. ASR wells are also found in areas that have no fresh water drinking water supply, or in coastal areas where salt water intrusion into freshwater aquifers is an issue. Densely developed areas tend to use recharge wells, while the Central and Western Plains States have more available open land and are more likely to use recharge basins and infiltration areas. As the population grows, as adequate land for the construction of surface reservoirs becomes increasingly scarce, and as water sources become more limited, the use of aquifer recharge and ASR wells is expected to increase.

Three studies looked at potential siting and future needs for artificial aquifer recharge. Culp (1981) developed water use and ground water mining projections for areas of the country and identified the Great Plains and the southwest United States as requiring recharge or some other action to alleviate water shortages. O'Hare et al. (1986) used a model based on agriculture needs to identify areas for aquifer recharge. The model identified central areas of the Great Plains and areas along the west and southeastern coasts of the United States. Fairchild (1985) identified areas suitable for aquifer recharge in combination with a need for preventing salt water intrusion. The areas suitable for recharge, according to Fairchild, corresponded to the same areas identified by O'Hare (1986): central areas of the Great Plains and areas along the west and southeastern coasts of the United States.

For this study, data on the number of Class V aquifer recharge and ASR wells were collected through a survey of state and USEPA Regional UIC Programs. The survey methods are summarized in Section 4 of Volume 1 of the Class V UIC Study. Table 1 lists the numbers of Class V aquifer recharge and ASR wells in each state, as determined from this survey. The table includes the documented number and estimated number of wells in each state, along with the source and basis for any estimate, when noted by the survey respondents. If a state is not listed in Table 1, it means that the UIC Program responsible for that state indicated in its survey response that it did not have any Class V aquifer recharge or ASR wells.

As shown in Table 1, there are approximately 1,185 aquifer recharge and ASR wells documented in the United States. This total includes 807 aquifer recharge wells, 130 ASR wells, and 248 recharge wells (in California and Idaho) that cannot be distinguished among aquifer recharge and ASR wells in the available inventory. The estimated number of aquifer recharge and ASR wells in the nation is believed to be greater than 1,695 (1,300 aquifer recharge wells, 147 ASR wells, and the 248 wells in California and Idaho that are either aquifer recharge or ASR wells. These estimates include 404 in Florida that were reported as aquifer recharge wells. However, there is a possibility that a high number of these 404 wells are storm drainage wells or

Table 1. Inventory of Aquifer Recharge and Aquifer Storage and Recovery Wells in the United States

State	Documented Number of Wells	Estimated Number of Wells		Type of Well (AR/ASR)
		Number	Source of Estimate and Methodology[1]	
USEPA Region 1				
NH	2	2	N/A	AR
USEPA Region 2				
NJ	NR	NR	N/A	AR
	10[2]	NR	N/A	ASR
NY	0	500	Best professional judgement.	AR
USEPA Region 3				
DE	2	2	N/A	ASR
PA	NR	NR	N/A	AR
VA	NR	NR	N/A	AR
	1[2]	NR	N/A	ASR
WV	1	1	State officials believe that the documented number of aquifer recharge wells in the state is accurate.	AR
USEPA Region 4				
FL	< 404	< 404	N/A	AR
	>84 wells at 28 facilities	>84 wells at 28 facilities (200 more wells to be built)	N/A	ASR
NC	0	0	Aquifer recharge wells are not being used to date, but state officials note that they are aware of plans to construct this type of well in the future.	AR
SC	55	55	N/A	AR
TN	1[3]	NR	N/A	ASR
USEPA Region 5				
IL	5	2	The Illinois Environmental Protection Agency has recent documentation for just two wells and believes that only two are still operating. The last correspondence on these wells was in May 1996.	AR
WI	1	1	One pilot test well approved conditionally as part of an American Water Works Association Research Foundation study (Wilson, 1999).	ASR

Table 1. Inventory of Aquifer Recharge and Aquifer Storage and Recovery Wells in the United States (continued)

State	Documented Number of Wells	Estimated Number of Wells		Type of Well (AR/ASR)
		Number	Source of Estimate and Methodology[1]	
USEPA Region 6				
OK	44	44	N/A	AR
TX	66	66	N/A	AR
	1	1	N/A	ASR
USEPA Region 7				
IA	1	1	N/A	ASR
KS	1	1	N/A	ASR
USEPA Region 8				
CO	2	NR	N/A	AR
	7	7	N/A	ASR
SD	1	1	N/A	AR
UT	3	> 3	Inventory forms received in fiscal year 1998 are not reflected in the documented number because of an anticipated change in data systems.	ASR
WY	3 wells/1 site (WDEQ) 6 sites (WY Database)	3 wells/1 site	Best professional judgement. The additional wells listed in the WY Database were never constructed or were closed shortly after commencing operations.	AR
USEPA Region 9				
AZ	2	> 2	Best professional judgement (Olson, 1999).	AR
CA	81 (Region 9) 200 (Central Valley Region)	81 (Region 9) 200 (Central Valley Region)	USEPA Region 9 does not distinguish between ASR and aquifer recharge wells; both are coded 5R21 in the inventory. Therefore, the exact number of ASR wells cannot be determined by examining the inventory. County and State Regional Water Quality Control Boards maintain Class V inventories. The extent to which USEPA Region 9 inventory data overlap county and state inventory data is unknown.	AR/ASR
GU	102	NR	Documented number of wells was obtained from Region database. However, Region acknowledges that this database is not entirely accurate because Guam was granted Primacy for the Class V UIC program in May 1983.	AR
NV	110	110	N/A	AR

Table 1. Inventory of Aquifer Recharge and Aquifer Storage and Recovery Wells in the United States (continued)

State	Documented Number of Wells	Estimated Number of Wells		Type of Well (AR/ASR)
		Number	Source of Estimate and Methodology[1]	
USEPA Region 10				
ID	48	48	This number combines ASR and aquifer recharge wells, both of which are coded as 5R21 wells in the available inventory (Terada, 1999).	AR/ASR
OR	4	0	Best professional judgement (Priest, 1999).	AR
	12	15	Best professional judgement (Priest, 1999).	ASR
WA	6	6	N/A	AR
	6	< 20	Best professional judgement.	ASR
All USEPA Regions				
All states	1,185 (807 AR, 130 ASR, and 248 AR/ASR)	> 1,695 (1,300 AR, 147 ASR, and 248 AR/ASR)	Total estimated number counts the documented number when estimate is NR. Estimated number of wells does not include 200 ASR wells proposed to be built in Florida as part of the new "Everglades Project."	AR and ASR

[1] Unless otherwise noted, the best professional judgement is that of the state or USEPA Regional staff completing the survey questionnaire.
[2] The number of documented wells was not reported by the USEPA Region or the state. Number of wells was obtained from literature.
[3] This injection well was permitted as an experimental well because, although ASR technology had been demonstrated in other states, this is the first such system to be constructed in Tennessee (TDEC, 1996a, 1996b).

AR Aquifer recharge well.

ASR Aquifer storage and recovery well.

N/A Not available.

NR Although USEPA Regional, state, and/or territorial officials reported the presence of the well type, the number of wells was not reported, or the questionnaire was not returned.

connector wells (Deuerling, 1999). It should also be noted that the estimated number of aquifer recharge and ASR wells does not include 200 ASR wells proposed to be built in Florida as part of the "Everglades Restoration Project."

The Everglades Restoration Project, officially known as the Central and South Florida (C&SF) Project, was authorized by Congress in 1948 and completed by the mid 1960s. It is a multi-purpose project that provides flood control; water supply for municipal, industrial, and agricultural uses; prevention of salt water intrusion; water supply for Everglades National Park; and protection of fish and wildlife resources. The primary system includes about 1,000 miles each of levees and canals, 150 water control structures, and 16 major pump stations. One set of problems has given way to a new set of equally critical problems that threatens the final collapse of what remains of the natural system, along with the resulting impacts to the population and economy of the region (U.S. Department of the Interior, 1996).

In 1993, the Army Corps of Engineers initiated a comprehensive review of the C&SF Project (C&SF Restudy), and a Federal Interagency Task Force, chaired by the Department of the Interior, was convened to coordinate ongoing restoration efforts and guide the Corps in its C&SF Restudy. The purpose of the C&SF Restudy was to determine the feasibility of structural or operational modifications to the project essential to restoration of the Everglades and Florida Bay ecosystems while providing for other water related needs including urban water supplies (U.S. Department of the Interior, 1996).

Additional information on ASR wells is provided in Attachments A and B of this volume. Attachment A provides the location, operational information, storage zone, and number of ASR wells, as reported in the literature, of some of the ASR facilities in the national inventory. Attachment B details the permitting and operational status, as well as type of injectate, of the 28 ASR facilities located in Florida.

4. INJECTATE CHARACTERISTICS AND INJECTION PRACTICES

4.1 Injectate Characteristics

4.1.1 Aquifer Recharge Wells

Sources of injectate in aquifer recharge wells known to exist in the United States are listed in Table 2. As shown in this table, aquifer recharge well injectate consists of treated drinking water, surface water (treated or untreated), surface runoff, and ground water (treated or untreated). Treated municipal wastewater (i.e., reclaimed water) also is being used for aquifer recharge, but wells injecting only this type of fluid are covered in the sewage treatment effluent well summary, which is Volume 7 of the Class V UIC Study.

Table 2: Source of Injectate for Aquifer Recharge Wells in the United States[1]

State	Source of Injectate
NH	Untreated surface (river) water that meets drinking water standards.
NJ	NR
NY	Untreated surface water.
PA	NR
VA	NR
WV	Treated drinking water.
FL	Treated surface water and reclaimed water.
NC	NR
SC	Surface water treated to drinking water standards.
IL	Surface water from the Illinois River.
OK	Unknown.
TX	Generally, overland flow.
CO	NR
SD	Surface water from the James River treated at the City of Huron Water Treatment Plant prior to injection.
WY	Fluids dewatered from a clinker unit of a surface coal mine.
AZ	Untreated surface water.
CA	Treated ground water.
NV	93 wells inject surface water with disinfection only. 17 wells inject untreated ground water at mine dewatering sites.
GU	NR
ID	47 wells inject untreated surface water. 1 well injects water treated to drinking water standards.
OR	3 wells inject shallow (<50 feet) ground water. 1 well injects surface water treated with disinfection only.
WA	Treated water. Treatment depends on background water quality.

[1] All data presented in the table were obtained from states and USEPA Regions.

NR Not reported.

Two aquifer recharge projects in the High Plains Region of the United States provide examples of the quality of water being injected into aquifer recharge wells. The first example is the Huron Project in South Dakota. This aquifer recharge project uses high flows from the James River during the spring runoff period as a source of water, treats this water in the City of Huron's water treatment plant, and injects the water into the Warren Aquifer. The Huron Project is one of the projects implemented by the Bureau of Reclamation and local sponsors in cooperation with USEPA and the United States Geological Survey under the "High Plains States Ground Water Demonstration Program Act of 1983," Public Law 98-434 (the Act). The Act authorizes and directs the Secretary of the Interior, acting through the Bureau of Reclamation, to engage in a special study of the potential for ground water recharge in the High Plains States (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming) and other Reclamation Act States (Arizona, California, Idaho, Montana, Nevada, North Dakota, Oregon, Utah, and Washington) (Schaefer et al., 1994). The primary purpose of the Act is to advance the state-of-the-art in ground water recharge techniques (U.S. Bureau of Reclamation, 1996). For each demonstration program established under the Act, monitoring data have to be collected for a period of four to five years and a final report has to be submitted to Congress. A summary report will be submitted to Congress at the conclusion of the demonstration projects, currently estimated to be early in fiscal year 2000 (U.S. Bureau of Reclamation, No date #1).

Injectate data for the Huron Project in South Dakota, along with drinking water standards for the purpose of comparison, are presented in Table 3. As seen in the table, all constituents analyzed, except fluoride, meet primary and secondary drinking water standards. For fluoride, concentrations ranging between 8 and 14 mg/l were measured. The primary drinking water standard for fluoride is 4 mg/l.

The second example is the use of aquifer recharge wells in the High Plains Region of Texas. This type of well is used to recharge ground water aquifers when surface water is in surplus. Constituent concentrations in waters of the High Plains Aquifer and in recharge waters are presented in Table 4. Comparison of constituent concentrations in aquifer waters with corresponding recharge waters suggest that the injected water may often be of better quality than that of the receiving aquifer. In addition, all constituents in the recharge waters, for which chemical analysis data are available, meet drinking water standards. The only exception is the recharge waters of Hockley County for which the pH was 9. The secondary drinking water standard for pH is 6.5 to 8.5.

Table 3. Injectate Data for Recharge Water Used in the Huron Project

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Range of Concentrations (mg/l, unless otherwise indicated)
Organics			
Benzene	0.005 (F)	0.1 (F,C)	<0.003
Carbon Tetrachloride	0.005 (F)	0.03 (F,C)	<0.003
1,2-Dichlorobenzene	0.6 (F)	0.6 (F,N)	<0.003
1,3-Dichlorobenzene	N/A	0.6 (F,N)	<0.003
1,4-Dichlorobenzene	0.075 (F)	0.075 (F,N)	<0.003
1,2-Dichloroethane	0.005 (F)	0.04 (F,C)	<0.003
1,1-Dichloroethylene	0.007 (F)	0.007 (F,N)	<0.003
1,1,1-Trichloroethane	0.2 (F)	0.2 (F,N)	<0.003
Trichloroethylene	0.005 (F)	0.3 (F,C)	<0.003
Vinyl Chloride	0.002 (F)	0.0015 (F,C)	<0.001
2,4-D	0.07 (F)	0.07 (F,N)	<0.00001 - 0.00025
2,4,5-T	L	0.07 (F,N)	<0.00001 - 0.00001
2,4-DP	N/A	N/A	<0.00001 - 0.00001
Aldrin	N/A	0.0002 (D,C)	<0.00001 - 0.00001
Chlordane	0.002 (F)	0.003 (F,C)	<0.00001 - 0.0001
DDD	N/A	N/A	<0.00001 - 0.00001
DDE	N/A	N/A	<0.00001 - 0.00001
DDT	N/A	N/A	<0.00001 - 0.00001
Dieldrin	N/A	0.0002 (F,C)	<0.00001 - 0.00001
Endosulfan I	N/A	N/A	<0.00001 - 0.00001
Endrin	0.002 (F)	0.002 (F,N)	<0.00001 - 0.00001
Heptachlor	0.0004 (F)	0.0008 (F,C)	<0.00001 - 0.00001
Heptachlor Epoxide	0.0002 (F)	0.0004 (F,C)	<0.00001 - 0.00001
Lindane	0.0002 (F)	0.0002 (F,N)	<0.00001 - 0.00001
Methoxychlor	0.04 (F)	0.04 (F,N)	<0.00001 - 0.00001
Mirex	N/A	N/A	<0.00001 - 0.00001
Perthane	N/A	N/A	<0.0001 - 0.0001

Table 3. Injectate Data for Recharge Water Used in the Huron Project (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Range of Concentrations (mg/l, unless otherwise indicated)
Polychlorobiphenyls	0.0005 (F)	0.0005 (P,C)	<0.0001 - 0.0001
Polychlorophthalenes	N/A	N/A	<0.0001 - 0.0001
Silvex (2,4,5-TP)	0.05 (F)	0.05 (F,N)	<0.00001 - 0.00001
Toxaphene	0.003 (F)	0.003 (F,C)	<0.001 - 0.001
Dichlorobromomethane	N/A	N/A	0.0075 - 0.021
Bromoform	0.1 (P)	0.4 (D,C)	<0.003
Chlorodibromomethane	0.1 (P)	0.06 (D,N)	0.0035 - 0.017
Chloroform	0.1 (P)	0.6 (D,C)	0.0093 - 0.021
Inorganics			
Arsenic	0.05 (R)	0.002 (D,C)	<0.001
Barium	2 (F)	2 (F,N)	0.012 - 0.020
Beryllium	0.004 (F)	0.0008 (D,C)	<0.0005
Boron	L	0.6 (D,N)	0.2 - 0.4
Cadmium	0.005 (F)	0.005 (F,N)	<0.001
Calcium	N/A	N/A	37 - 53
Chloride	Secondary MCL: 250 (F)	N/A	69 - 100
Chromium	0.1 (F)	0.1 (F,N)	<0.005
Cobalt	N/A	N/A	<0.003
Copper	1.3 (F) (action level, at tap) Secondary MCL: 1 (F)	N/A	<0.01
Fluoride	4 (F,R) Secondary MCL: 2 (F)	N/A	8 - 14 **i**
Iron	Secondary MCL: 0.3 (F)	N/A	0.005 - 0.009
Lead	0.015 (action level, at tap) (F)	N/A	<0.01
Lithium	N/A	N/A	0.05 - 0.07
Magnesium	N/A	N/A	12 - 20
Manganese	L Secondary MCL: 0.05 (F)	N/A	0.002 - 0.003
Mercury	0.002 (F)	0.002 (F,N)	<0.0001
Molybdenum	L	0.04 (D,N)	<0.01 - 0.01
Nickel	0.1 (F)[2]	0.1 (F,N)	<0.01

Table 3. Injectate Data for Recharge Water Used in the Huron Project (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Range of Concentrations (mg/l, unless otherwise indicated)
Ammonia	N/A	30 (D,N)	0.59 - 0.98
Nitrate, as N	10 (F)	N/A	<0.1 - 0.1
Phosphorus	N/A	N/A	0.578 - 0.593
Orthophosphorus	N/A	N/A	0.02 - 0.063
Potassium	N/A	N/A	17 - 23
Selenium	0.05 (F)	N/A	<0.001
Silica	N/A	N/A	4.6 - 8.8
Silver	Secondary MCL: 0.1 (F)	0.1 (D,N)	<0.001
Sodium	N/A	D	100 - 190
Strontium	N/A	N/A	0.24 - 0.37
Sulfate	500 (P) Secondary MCL: 250 (F)	D	230 - 440
Vanadium	T	D	<0.006
Zinc	L Secondary MCL: 5 (F)	2 (D,N)	<0.003 -0.004
Radionuclides			
Gross Beta, as CS-137	4 mrem/y (27.7 pCi/l) (F)	4 mrem/y (27.7 pCi/l) (C)	7.5 - 24 pCi/l
Gross Beta, as SR/YT-90	4 mrem/y (27.7 pCi/l) (F)	4 mrem/y (27.7 pCi/l) (C)	5.6 - 18 pCi/l
Gross Alpha, as U-Nat	15 pCi/l (F)	15 pCi/l (C)	<0.4 - 1.2 pCi/l
Radium 226/228	Combined Radium 226 and 228: 5 pCi/l (F)	Combined Radium 226 and 228: 20 pCi/l (C)	0.1/0 pCi/l

Data Sources: South Dakota State University, 1993 and U.S. Bureau of Reclamation, No date #2

[1] Primary maximum contaminant level (MCL), unless otherwise noted.
[2] Being remanded.

Regulatory Status:

F	Final	P	Proposed
D	Draft	R	Under Review
L	Listed for regulation	T	Tentative (not officially proposed)

Health Advisory:

C	10^{-4} cancer risk	N	Noncancer lifetime

N/A Not available.

i Exceeds primary and secondary drinking water standards.

Table 4. Constituent Concentrations in Aquifer and Recharge Waters, High Plains Aquifer, TX

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentrations at Dawson County Well[2] (mg/l, unless otherwise indicated)		Concentrations at Hockley County Well[2] (mg/l, unless otherwise indicated)		Concentrations at Edwards County Well[3] (mg/l, unless otherwise indicated)	
			Aquifer Waters	Recharge Waters	Aquifer Waters	Recharge Waters	Aquifer Waters	Recharge Waters
Nitrate	10 (F)	N/A	43	0.04	8.4	0.04	7.2	0.04
Silica	N/A	N/A	70	2	50	2	11	11
Calcium	N/A	N/A	61	39	60	27	63	60
Magnesium	N/A	N/A	53	3	88	7	8	1
Sodium	N/A	D	65	25	61	15	8	6
Potassium	N/A	N/A	8	6	—	6	—	12
Carbonate	N/A	N/A	—	0	—	6	—	0
Bicarbonate	N/A	N/A	375	113	337	87	211	183
Sulfate	500 (P) Secondary MCL: 250 (F)	D	81	32	218	24	7	10
Chloride	Secondary MCL: 250 (F)	N/A	68	33	86	20	15	15
Fluoride	4 (F,R) Secondary MCL: 2 (F)	N/A	4.5	0.3	4.4	0.5	0.2	0.1
pH	Secondary MCL: 6.5 - 8.5	N/A	7.8	8.3	8.4	9 **i**	8.1	8
Total Dissolved Solids	Secondary MCL: 500 (F)	N/A	637.8	206	741.5	154	223.1	222

Data Source: Texas Department of Water Resources, 1984
[1] Primary maximum contaminant level (MCL), unless otherwise noted.
[2] Ogallala Aquifer.
[3] Edwards Aquifer.
Regulatory Status: F: Final; D: Draft; R: Under Review
N/A Not available.
i Exceeds secondary drinking water standard.

4.1.2 ASR Wells

Sources of injectate in ASR wells known to exist in the United States are listed in Table 5. As shown in the table, ASR well injectate consists of potable drinking water (from a drinking water plant), surface water (treated or untreated), ground water (treated or untreated), and reclaimed water. For further discussion on ASR wells injecting reclaimed water, see the sewage treatment effluent well summary, which is Volume 7 of the Class V UIC Study.

Table 5: Source of Injectate for ASR Wells in the United States[1]

State	Source of Injectate
NJ	NR
DE	Ground water from another aquifer; the water may be treated and disinfected.
VA	NR
FL	Treated potable drinking water (from a drinking water plant), untreated (raw) ground water, untreated (raw) surface water, reclaimed water, and partially treated surface water.
WI	Surface water treated to drinking water standards.
TX	Surface water treated to drinking water standards.
IA	Surface water treated to drinking water standards.
KS	Untreated ground water infiltrated from the Little Arkansas River.
CO	Surface water treated to drinking water standards.
UT	Surface and spring water treated to drinking water standards.
CA	Treated ground water.
OR	Surface water treated to drinking water standards.
WA	Surface water treated to drinking water standards. The Washington State Legislature recently authorized injection of treated wastewater (tertiary treatment) on a pilot basis. To the state's knowledge, none of this type of well currently exists, but activity is expected in the near future.

[1] All data presented in the table were obtained from states and USEPA Regions.
NR Not reported.

In cases where injectate constituents react with ambient ground water causing an increase in constituent concentrations or the formation of new compounds, pretreatment techniques are used. For example, injectate of ASR wells at the Swimming River site in New Jersey is pretreated in order to control excessive iron concentrations (i.e., concentrations above secondary drinking water standards) in the recovered water. These techniques involve lowering pH to control the precipitation of ferric hydroxide floc in the aquifer, followed by a buffer volume of deoxygenated water at normal pH.

To provide a representative characterization of the injectate used in ASR operations, injectate data from four facilities are summarized in Tables 6 through 8. For the purpose of comparison, the tables also present available drinking water standards. A brief discussion of these data follows.

Table 6 presents injectate data for the ASR wells operated by the Centennial Water and Sanitation District, Denver, Colorado. The injectate in these wells is treated surface water and treated ground water, when surface water is not readily available. As shown in this table, the only two constituents that do not meet the primary drinking water standards are radium and lead. For radium (radium 226 and 228), a concentration of 5.03 pCi/l was found during one of the sample events (July 28, 1998). The primary drinking water standard for combined radium 226 and 228 is 5 pCi/l. For lead, a concentration of 0.025 mg/l was found in one of the samples (February 11, 1998). The action level for lead is 0.015 mg/l, at the tap.

Table 7 presents injectate data for the four ASR wells at Woodmansee Park in the City of Salem, Oregon. These ASR wells, which inject treated surface water, are being used as a secondary source of water for emergency needs and for supplemental needs during high water use summer seasons. As shown in the table, all constituents analyzed meet drinking water standards.

Table 8 presents injectate data for the ASR well operated by the Memphis Light, Gas, and Water Division (MLGWD). This well injects treated drinking water. As shown in Table 8, the injectate meets primary drinking water standards for all constituents analyzed.

As mentioned earlier, 200 new ASR wells have been proposed to be used as part of the C&SF Restudy. These wells would inject untreated surface water, which will not meet primary or secondary drinking water standards at the point of discharge (Wilson, 1999).

Table 6. Injectate Data for the ASR System at Centennial Water and Sanitation District, Highlands Ranch, Colorado

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Range of Concentrations (mg/l, unless otherwise indicated)
Volatile Organic Chemicals			
Benzene	0.005 (F)	0.1 (F,C)	<MDL
Bromobenzene	L	D	<MDL
Bromodichloromethane	0.1 (P)	0.06 (D,C)	0.011 - 0.027
Bromoform	0.1 (P)	0.4 (D,C)	0.0011 - 0.0066
Bromomethane	T	0.01 (D,N)	<MDL
Carbon Tetrachloride	0.005 (F)	0.03 (F,C)	<MDL
Chlorobenzene	N/A	N/A	<MDL
Chloroethane	L	D	<MDL
Chloroform	0.1 (P)	0.6 (D,C)	0.011 - 0.018
Chloromethane	L	0.003 (F,N)	<MDL
o-Chlorotoluene	L	0.1 (F,N)	<MDL
p-Chlorotoluene	L	0.1 (F,N)	<MDL
Dibromomethane	L	N/A	<MDL
m-Dichlorobenzene (1,3-Dichlorobenzene)	N/A	0.6 (F,N)	<MDL
o-Dichlorobenzene (1,2-Dichlorobenzene)	0.6 (F)	0.6 (F,N)	<MDL
p-Dichlorobenzene (1,4-Dichlorobenzene)	0.075 (F)	0.075 (F,N)	<MDL
1,1-Dichloroethane	N/A	N/A	<MDL
1,2-Dichloroethane	0.005 (F)	0.04 (F,C)	<MDL
1,1-Dichloroethylene	0.007 (F)	0.007 (F,N)	<MDL
cis-1,2-Dichloroethylene	0.07 (F)	0.07 (F,N)	<MDL
trans-1,2-Dichloroethylene	0.1 (F)	0.1 (F,N)	<MDL
Dichloromethane (Methylene Chloride)	0.005 (F)	0.5 (F,C)	<MDL
1,2-Dichloropropane	0.005 (F)	0.06 (F,C)	<MDL
1,3-Dichloropropane	L	D	<MDL
2,2-Dichloropropane	L	D	<MDL
1,1-Dichloropropene	N/A	D	<MDL

Table 6. Injectate Data for the ASR System at Centennial Water and Sanitation District, Highlands Ranch, Colorado (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Range of Concentrations (mg/l, unless otherwise indicated)
1,3-Dichloropropene	T	0.02 (F,C)	<MDL
Ethylbenzene	0.7 (F)	0.7 (F,N)	<MDL
Styrene	0.1 (F)	0.1 (F,N)	<MDL
1,1,1,2-Tetrachloroethane	L	0.07 (F,N) 0.1 (F,C)	<MDL
1,1,2,2-Tetrachloroethane	L	D	<MDL
Tetrachloroethylene	0.005 (F)	0.07 (F,C)	<MDL
Toluene	1 (F)	1 (F,N)	<MDL
1,1,2-Trichloroethane	0.005 (F)	0.003 (F,N)	<MDL
Trichloroethylene	0.005 (F)	0.3 (F,C)	<MDL
1,2,3-Trichloropropane	L	0.04 (F,N) 0.5 (F,C)	<MDL
Vinyl Chloride	0.002 (F)	0.0015 (F,C)	<MDL
m-Xylene	10 (F)[2]	10 (F,N)[3]	<MDL
o-Xylene	10 (F)[2]	10 (F,N)[3]	<MDL
p-Xylene	10 (F)[2]	10 (F,N)[3]	<MDL
Inorganics			
Arsenic, As (T)	0.05 (R)	0.002 (D,C)	<MDL - 0.002
Barium, Ba (T)	2 (F)	2 (F,N)	0.057 - 0.074
Cadmium, Cd (T)	0.005 (F)	0.005 (F,N)	<MDL - 0.0001
Chromium, Cr (T)	0.1 (F)	0.1 (F,N)	<MDL
Lead, Pb (T)	0.015 (action level, at tap) (F)	N/A	<MDL - 0.025 **i**
Mercury, Hg (T)	0.002 (F)	0.002 (F,N)	<MDL
Selenium, Se (T)	0.05 (F)	N/A	<MDL - 0.011
Silver, Ag (T)	Secondary MCL: 0.1 (F)	0.1 (D,N)	<MDL - 0.0003
Sodium, Na (T)	N/A	D	0.0197 - 0.046
Fluoride, F	4 (F,R) Secondary MCL: 2 (F)	N/A	0.00083 - 0.00089
Nitrogen, Nitrate	10 (F)	N/A	0.00009 - 0.00044

Table 6. Injectate Data for the ASR System
at Centennial Water and Sanitation District, Highlands Ranch, Colorado (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Range of Concentrations (mg/l, unless otherwise indicated)
Radionuclides			
Gross Alpha	15 pCi/l (F)	15 pCi/l (C)	5.3 - 13.8 pCi/l
Gross Beta	4 mrem/y (27.7 pCi/l) (F)	4 mrem/y (27.7 pCi/l) (C)	5.2 - 12.4 pCi/l
Radium 226	Combined Radium 226 and 228: 5 pCi/l (F)	Combined Radium 226 and 228: 20 pCi/l (C)	0.31 - 2.42 pCi/l **i**
Radium 228			1.0 - 2.61 pCi/l **i**
Pesticides			
Endrin	0.002 (F)	0.002 (F,N)	<MDL
Lindane	0.0002 (F)	0.0002 (F,N)	<MDL
Methoxychlor	0.04 (F)	0.04 (F,N)	<MDL
Toxaphene	0.003 (F)	0.003 (F,C)	<MDL
Herbicide			
2,4-D	0.07 (F)	0.07 (F,N)	<MDL
2,4,5-TP (Silvex)	L	0.07 (F,N)	<MDL

Data source: Centennial Water and Sanitation District, 1998

[1] Primary maximum contaminant level (MCL), unless otherwise noted.
[2] Primary MCL established for total xylenes.
[3] Health advisory level established for total xylenes.

Regulatory Status:

F	Final	P	Proposed
D	Draft	R	Under Review
L	Listed for regulation	T	Tentative (not officially proposed)

Health Advisory:

C	10^{-4} cancer risk	N	Noncancer lifetime

<MDL Less than method detection level.

N/A Not applicable.

i Exceeds primary drinking water standard.

Table 7. Injectate Data for ASR System in City of Salem, Oregon

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
Organics			
Benzene	0.005 (F)	0.1 (F,C)	<MDL
Carbon Tetrachloride	0.005 (F)	0.03 (F,C)	<MDL
Chlorobenzene	N/A	N/A	<MDL
1,2-Dichlorobenzene	0.6 (F)	0.6 (F,N)	<MDL
1,4-Dichlorobenzene	0.075 (F)	0.075 (F,N)	<MDL
1,2-Dichloroethane	0.005 (F)	0.04 (F,C)	<MDL
1,1-Dichloroethylene	0.007 (F)	0.007 (F,N)	<MDL
cis-1,2-Dichloroethylene	0.07 (F)	0.07 (F,N)	<MDL
trans-1,2-Dichloroethylene	0.1 (F)	0.1 (F,N)	<MDL
Dichloromethane (Methylene Chloride)	0.005 (F)	0.5 (F,C)	<MDL
1,2-Dichloropropane	0.005 (F)	0.06 (F,C)	<MDL
Ethylbenzene	0.7 (F)	0.7 (F,N)	<MDL
Styrene	0.1 (F)	0.1 (F,N)	<MDL
Tetrachloroethylene	0.005 (F)	0.07 (F,C)	<MDL
Toluene	1 (F)	1 (F,N)	<MDL
1,2,4-Trichlorobenzene	0.07 (F)	0.07 (F,N)	<MDL
1,1,1-Trichloroethane	0.2 (F)	0.2 (F,N)	<MDL
1,1,2-Trichloroethane	0.005 (F)	0.003 (F,N)	<MDL
Trichloroethylene	0.005 (F)	0.3 (F,C)	<MDL
Vinyl Chloride	0.002 (F)	0.0015 (F,C)	<MDL
Xylenes	10 (F)	10 (F,N)	<MDL
Bromobenzene	L	D	<MDL
Bromodichloromethane	0.1 (P)	0.06 (D,N)	<MDL
Bromoform	0.1 (P)	0.4 (D,C)	<MDL
Bromomethane	T	0.01 (D,N)	<MDL

Table 7. Injectate Data for ASR System in City of Salem, Oregon (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
Chloroethane	L	D	<MDL
Chloroform	0.1 (P)	0.6 (D,C)	0.011
Chloromethane	L	0.003 (F,N)	<MDL
2,4-D	0.07 (F)	0.07 (F,N)	<MDL
Silvex (2,4,5-TP)	0.05 (F)	0.05 (F,N)	<MDL
Aldrin	N/A	0.0002 (D,C)	<MDL
Chlordane	0.002 (F)	0.003 (F,C)	<MDL
Dieldrin	N/A	0.0002 (F,C)	<MDL
Endrin	0.002 (F)	0.002 (F,N)	<MDL
Heptachlor	0.0004 (F)	0.0008 (F,C)	<MDL
Heptachlor Epoxide	0.0002 (F)	0.0004 (F,C)	<MDL
Lindane	0.0002 (F)	0.0002 (F,N)	<MDL
Methoxychlor	0.04 (F)	0.04 (F,N)	<MDL
Toxaphene	0.003 (F)	0.003 (F,C)	<MDL
Inorganics			
Antimony	0.006 (F)	0.003 (F,N)	<MDL
Arsenic	0.05 (R)	0.002 (D,C)	<MDL
Barium	2 (F)	2 (F,N)	0.0011
Beryllium	0.004 (F)	0.0008 (D,C)	<MDL
Cadmium	0.005 (F)	0.005 (F,N)	<MDL
Calcium	N/A	N/A	3.6
Chloride	Secondary MCL: 250 (F)	N/A	2.3
Chromium	0.1 (F)	0.1 (F,N)	<MDL
Copper	1.3 (action level, at tap) (F) Secondary MCL: 1 (F)	N/A	0.01
Fluoride	4 (F,R) Secondary MCL: 2 (F)	N/A	0.8
Iron	Secondary MCL: 0.3 (F)	N/A	<MDL

Table 7. Injectate Data for ASR System in City of Salem, Oregon (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
Lead	0.015 (action level, at tap) (F)	N/A	0.0003
Magnesium	N/A	N/A	1.1
Manganese	L Secondary MCL: 0.05 (F)	N/A	0.0005
Mercury	0.002 (F)	0.002 (F,N)	<MDL
Nickel	0.1 (F)[2]	0.1 (F,N)	<MDL
Nitrate, as N	10 (F)	N/A	0.04
Potassium	N/A	N/A	0.5
Selenium	0.05 (F)	N/A	<MDL
Silica	N/A	N/A	13
Silver	Secondary MCL: 0.1 (F)	0.1 (D,N)	<MDL
Sodium	N/A	D	3
Sulfate	500 (P) Secondary MCL: 250 (F)	D	0.8
Zinc	L Secondary MCL: 5 (F)	2 (D,N)	<MDL
Radionuclides			
Gross Beta, as CS-137	4 mrem/y (27.7 pCi/l) (F)	4 mrem/y (27.7 pCi/l) (C)	<MDL
Gross Beta, as SR/YT-90	4 mrem/y (27.7 pCi/l) (F)	4 mrem/y (27.7 pCi/l) (C)	<MDL
Radium 226/228	Combined Radium 226 and 228: 5 pCi/l (F)	Combined Radium 226 and 228: 20 pCi/l (C)	<MDL
Uranium	0.02 mg/l (P)	R	0.000004 mg/l
Microbiological Data			
Total Coliform	5/100 ml	N/A	Absent
E. Coli	5/100 ml	N/A	Absent

Table 7. Injectate Data for ASR System in City of Salem, Oregon (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
Other Parameters			
Alkalinity	N/A	N/A	15
Conductivity	N/A	N/A	44 uhmos/cm
Hardness	N/A	N/A	14
pH	Secondary MCL: 6.5 - 8.5	N/A	7.02
Total Dissolved Solids	Secondary MCL: 500 (F)	N/A	25
Turbidity	N/A	N/A	0.27 NTU

Data Sources: City of Salem, 1999

[1] Primary maximum contaminant level (MCL), unless otherwise noted.
[2] Being remanded.

Regulatory Status:

F	Final	D	Draft
L	Listed for regulation	P	Proposed
R	Under Review	T	Tentative (not officially proposed)

Health Advisory:

C	10^{-4} cancer risk	N	Noncancer lifetime

<MDL Less than method detection level.

N/A Not available.

Table 8. Injectate Data for the ASR System
Operated by the Memphis Light, Gas, and Water Division in Tennessee

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
Volatile Organic Chemicals			
Benzene	0.005 (F)	0.1 (F,C)	<MDL
Bromodichloromethane	0.1 (P)	0.06 (D,N)	0.001
Bromoform	0.1 (P)	0.4 (D,C)	0.0005
Carbon Tetrachloride	0.005 (F)	0.03 (F,C)	<MDL
Chloroform	0.1 (P)	0.6 (D,C)	0.0008
Dibromochloromethane	0.1 (P)	0.06 (D,N)	0.0075 - 0.029
Dibromochloropropane	0.0002 (F)	0.003 (F,C)	<MDL
1,2-Dibromoethane	N/A	N/A	<MDL
o-Dichlorobenzene (1,2-Dichlorobenzene)	0.6 (F)	0.6 (F,N)	<MDL
p-Dichlorobenzene (1,4-Dichlorobenzene)	0.075 (F)	0.075 (F,N)	<MDL
1,1-Dichloroethane	N/A	N/A	<MDL
1,2-Dichloroethane	0.005 (F)	0.04 (F,C)	<MDL
1,1-Dichloroethylene	0.007 (F)	0.007 (F,N)	<MDL
cis-1,2-Dichloroethylene	0.07 (F)	0.07 (F,N)	<MDL
trans-1,2-Dichloroethylene	0.1 (F)	0.1 (F,N)	<MDL
Dichloromethane (Methylene Chloride)	0.005 (F)	0.5 (F,C)	<MDL
1,2-Dichloropropane	0.005 (F)	0.06 (F,C)	<MDL
Ethylbenzene	0.7 (F)	0.7 (F,N)	<MDL
Monochlorobenzene	0.1 (F)	0.1 (F,N)	<MDL
Styrene	0.1 (F)	0.1 (F,N)	<MDL
1,1,1,2-Tetrachloroethane	L	0.07 (F,N) 0.1 (F,C)	<MDL
1,1,2,2-Tetrachloroethane	L	D	<MDL
Tetrachloroethylene	0.005 (F)	0.07 (F,C)	<MDL
Toluene	1 (F)	1 (F,N)	<MDL
1,2,3-Trichlorobenzene	N/A	N/A	<MDL

Table 8. Injectate Data for the Aquifer Storage and Recovery System Operated by the Memphis Light, Gas, and Water Division in Tennessee (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
1,2,4-Trichlorobenzene	0.07 (F)	0.07 (F,N)	<MDL
1,1,1-Trichloroethane	0.2 (F)	0.2 (F,N)	<MDL
1,1,2-Trichloroethane	0.005 (F)	0.003 (F,N)	<MDL
Trichloroethylene	0.005 (F)	0.3 (F,C)	<MDL
1,2,3-Trichloropropane	L	0.04 (F,N) 0.5 (F,C)	<MDL
1,2,4-Trimethylbenzene	N/A	D	<MDL
Vinyl Chloride	0.002 (F)	0.0015 (F,C)	<MDL
Xylenes	10 (F)	10 (F,N)	<MDL
Inorganics			
Antimony	0.006 (F)	0.003 (F,N)	<MDL
Arsenic	0.05 (R)	0.002 (D,C)	<MDL
Barium	2 (F)	2 (F,N)	0.042
Beryllium	0.004 (F)	0.0008 (D,C)	<MDL
Cadmium	0.005 (F)	0.005 (F,N)	<MDL
Carbon Dioxide	N/A	N/A	12
Chloride	Secondary MCL: 250 (F)	N/A	4.9
Chromium	0.1 (F)	0.1 (F,N)	<MDL
Copper	1.3 (action level, at tap) (F) Secondary MCL: 1 (F)	N/A	<MDL
Fluoride	4 (F,R) Secondary MCL: 2 (F)	N/A	0.96
Iron	Secondary MCL: 0.3 (F)	N/A	0.04
Lead	0.015 (action level, at tap) (F)	N/A	<MDL
Manganese	L Secondary MCL: 0.05 (F)	N/A	0.004
Mercury	0.002 (F)	0.002 (F,N)	<MDL
Molybdenum	L	0.04 (D,N)	<MDL
Nickel	0.1 (F)[2]	0.1 (F,N)	<MDL
Nitrate (as N)	10 (F)	N/A	0.9

Table 8. Injectate Data for the Aquifer Storage and Recovery System Operated by the Memphis Light, Gas, and Water Division in Tennessee (continued)

Parameter	Drinking Water Standard[1] (mg/l, unless otherwise indicated)	Health Advisory Level (mg/l, unless otherwise indicated)	Concentration (mg/l, unless otherwise indicated)
Phosphate	N/A	N/A	1
Selenium	0.05 (F)	N/A	<MDL
Silica	N/A	N/A	13.8
Sulfate	500 (P) Secondary MCL: 250 (F)	D	3.6
Thallium	0.002 (F)	0.0005 (F,N)	<MDL
Zinc	L Secondary MCL: 5 (F)	2 (D,N)	<MDL
Other Parameters			
Alkalinity	N/A	N/A	54
Conductivity	N/A	N/A	133.2 uhmos
Dissolved Oxygen	N/A	N/A	8.4
Hardness	N/A	N/A	49
pH	Secondary MCL: 6.5 - 8.5	N/A	7.08
Temperature	N/A	N/A	20.6
Total Dissolved Solids	Secondary MCL: 500 (F)	N/A	77

Data source: MGLWD, 1997

[1] Primary maximum contaminant level (MCL), unless otherwise noted.
[2] Being remanded.

Regulatory Status:

F	Final	D	Draft
L	Listed for regulation	P	Proposed
R	Under Review		

Health Advisory:

C	10^{-4} cancer risk	N	Noncancer lifetime

<MDL Less than method detection level.

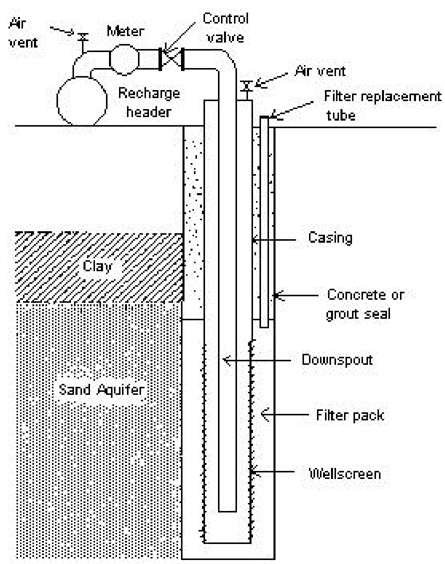
N/A Not applicable.

4.2 Well Characteristics

4.2.1 Design Features

Although the design and construction of aquifer recharge and ASR wells depend on site-specific conditions and the intended use of the recharged water after withdrawal (e.g., drinking water versus agricultural water), the components of most recharge wells are very similar. These include: (1) the well casing; (2) the well screen (except in rock and other open hole wells); (3) sand/gravel (filter) pack around the screen (except in rock and other open hole wells); (4) grout/cement around the casing; and (5) a pump. Figure 1 illustrates a typical recharge well. Figure 2 shows schematics of a typical ASR well.

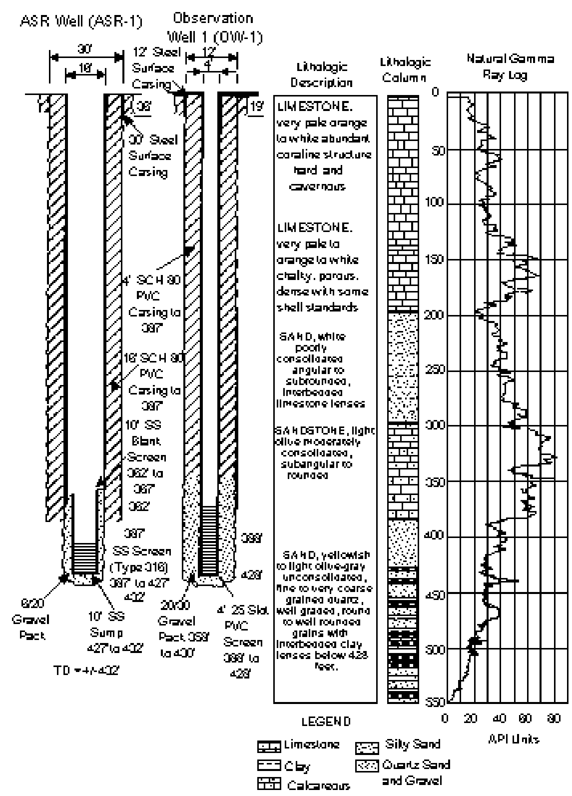
Figure 1. Typical Recharge Well



Powers, 1992

Figure 2. Typical ASR Well

Source:

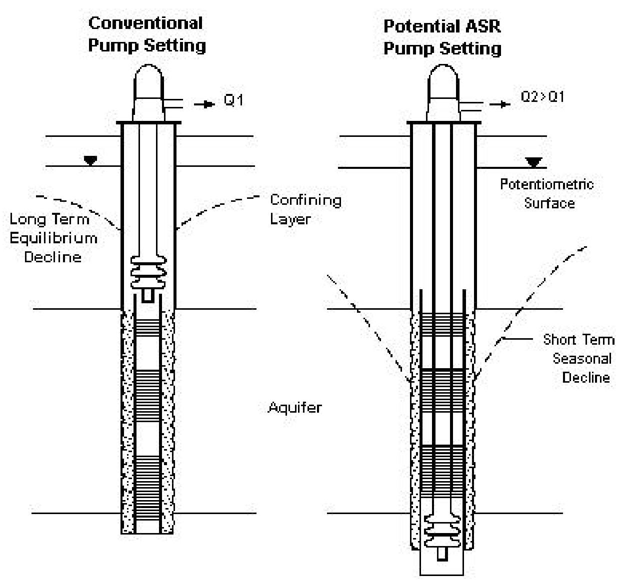


Source: Pyne, 1995 (ASR well in Marathon, Florida)

Uncoated steel casing is typically used in the construction of injection wells. However, steel-cased ASR wells are more vulnerable to rusting than most other injection wells because alternating periods of recharge and recovery during ASR operations expose a large surface area to frequent wetting and drying. This frequent wetting and drying causes rust to form on the inside of the well. During recharge periods, the rust becomes suspended in injection water with other solids and contributes to well clogging. To avoid this problem, ASR wells may be constructed using material that will not contribute to the production of rust—in particular, polyvinyl chloride (PVC). However, if steel casing is required, epoxy coating can substantially reduce the surface area of steel subject to rusting. These two approaches have been proven to be successful in operational ASR systems. Other materials that could be used in the construction of ASR well casings are fiberglass and stainless steel, but they are more expensive alternatives. One example of the use of stainless steel in the construction of ASR wells is a well in the city of Delray Beach, Florida. That ASR well has a type 316 stainless steel final casing to protect against electrolysis.

In an ASR system, the proper selection of the pumping equipment is of prime importance because the same well-pump combination will be used for recharge and recovery purposes. Submersible pumps are often used in ASR wells for recovery of stored water. Conventionally, ASR systems place the pump at the base of the casing, above the well screen. While this design has been successful in the past, a new design alternative has been suggested. In this alternative, the pump is placed below the screen interval at the bottom of the well. Figure 3 shows the two design options.

Figure 3. Alternative Pump Setting for ASR Wells



Source: Pyne, 1995

It should be noted that the above description covers the most common well design. However, wells could be constructed using other designs, such as slant or horizontal casings or multiple casings nested on a single bore hole to control injection into specific aquifer zones.

4.2.2 Siting Considerations

There are several factors that are common to the site selection process of all aquifer recharge and ASR wells. These include physical siting criteria, recharge water availability and quality, water demand (if applicable), regulatory and institutional issues, and economic considerations. A discussion of each of these factors follows.

Physical Siting Criteria

Under ideal conditions a well will accept recharge water at least as readily as it will yield water by pumping. However, actual conditions are never ideal. For that reason, it is common to conduct a hydrogeologic evaluation of the area. This evaluation provides the information necessary to select suitable storage zones, recharge water sources, and treatment requirements (if any). These hydrogeologic characteristics affect the location and design of the wells and have to be considered for a successful recharge project.

The hydrogeologic evaluation considers the following factors:

1. availability of an aquifer suitable for recharge;
2. aquifer areal extent, thickness, and depth;
3. geologic structure (unconsolidated, consolidated, fractures, bedding planes, fissures, etc.);
4. hydraulic characteristics (transmissivity, storativity, hydraulic conductivity, porosity, etc.);
5. mineralogy of clays, sands, and other soil components;
6. confining layers or aquitards (areal extent, thickness, and depth);
7. lithology of aquifer and confining layers;
8. chemical characteristics of the native ground water;
9. native ground water velocity and direction;
10. water table levels or potentiometric surface;
11. local gradient of the potentiometric surface;
12. geochemical compatibility of recharge and native water with formation minerals;
13. proximity of the potential recharge site to an appropriate well field cone of depression;
14. water level differences between the aquifer and the recharge site;
15. topography;
16. well inventory within a reasonable radius;
17. ground water withdrawals within the surrounding area;
18. proximity of potential sources of contamination; and
19. proximity of potential contamination plumes that may be affected by recharge operations (O’Hare, 1986).

In addition, delineated wellhead protection and source water protection areas should be taken into consideration for the siting of the wells.

In short, there are many hydrogeologic characteristics to be considered when determining if a particular site will be suitable for artificial recharge through recharge wells. After all applicable data are obtained, computer simulation modeling of the proposed recharge may be necessary and appropriate if there are any special concerns. Results of these analyses would be useful in deciding the location and design of the recharge wells.

Water Availability and Quality

The availability and quality of a source of water for artificial recharge also is an important factor in site selection. Many geographical areas that have demonstrated needs and many sites that are physically suitable for artificial recharge can never be developed due to lack of an acceptable water source. The types of water that may be considered for artificial recharge vary with the locality.

For water to qualify for consideration as a source water for artificial recharge, the chemical, physical, and biological characteristics are evaluated relative to the native water characteristics. This evaluation provides the information necessary to understand the interaction between the recharge and the native water, establish the criteria for the quality of the recharge water to prevent degradation in the quality of the native ground water, and determine if treatment of the recharge water is necessary.

Water Demand

If artificial recharge is used primarily as a water resource management tool, evaluation of water demands, including average demands, monthly variability, and trends is important in order to assess the duration of peak demand periods when recovery of stored water would provide maximum benefit.

Regulatory and Institutional Issues

Regulatory and institutional issues are also considered in artificial recharge site selection. These are particularly important because each state has its own requirements and procedures, as discussed in Section 7. In addition, the federal government (U.S. Bureau of Reclamation and U.S. Geological Survey) is involved in recharge activities through funding of local demonstration programs and state water projects, and USEPA or state UIC Primacy Programs have a say as part of their particular Class V programs. In some instances, consideration of local perspectives and relationships is also necessary.

Economic Considerations

Any proposed artificial recharge project first has to be evaluated relative to its effectiveness and economic justification. Thus, a preliminary estimate of the capital and operating cost of injection well operations is usually developed. Such analysis considers the useful life of the recharge project and the anticipated future availability of the recharge water source.

4.3 Operational Practices

As stated earlier, a recharge well may be defined as a well that is used to inject water (from the surface) to replenish the water in a fresh water aquifer. When water is injected into a recharge well, a mound in the potentiometric surface of a confined aquifer, or the water table of an unconfined aquifer, is created. The mound extends unsymmetrically in the direction of the regional flow in the aquifer. As injection continues, the areal extent of the mound spreads to occupy an ever-increasing area (Freeze and Cherry, 1979). This process forms a cone of recharge that is similar in shape but the reverse of a cone of depression surrounding a pumping well. Thus, this process may be viewed as the inverse of the effect of a pumping well in a confined aquifer, and, in fact, is described mathematically by the same equations, modified for the effect of injection rather than pumping (Warner, 1965). Additional information on this topic might be found in sources such as Driscoll (1986), O'Hare et al. (1986), and Todd (1980).

A number of factors affect recharge performance. Most of the problems in recharging through wells, especially in aquifers composed of fine-grained material, involve excessive buildup of water levels in the recharge well because of clogging of the well screen or aquifer. Injecting high-quality water reduces the frequency of well clogging, increases the operating life of the well, and reduces cleaning costs. In addition, chlorination of the injected water helps to protect the well casing, prevents potential leaks, and reduces nearfield biofouling of the formations (Bloetscher, 1999). However, even when using high-quality water, clogging is inevitable.

When there is clogging and the injection head has increased above acceptable levels (approximately every three years when using high-quality injectate water), redevelopment of the injection wells is necessary (Bruington, 1968). Redevelopment of a well involves the removal of finer material from the natural formations surrounding the perforated sections of the casing. Periodic redevelopment of the well is used to restore its efficiency and specific capacity. Thorough initial development of the injection wells will delay the need for redevelopment and increase the initial specific capacity of the well, making it more efficient (Bruington, 1968).

Calibration of flow meters and other equipment associated with the recharge well system is another standard operating procedure. Calibration is important to accurately keep track of flow rates in order to determine whether clogging is occurring and whether redevelopment is necessary.

A key factor in the operation of an ASR well is its recovery efficiency. Recovery efficiency is defined as the percentage of the water volume stored that is subsequently recovered while meeting a target water quality criterion in the recovered water (Pyne, 1995). According to Pyne (1995), recovery efficiency tends to improve with successive cycles when the same volume of water is stored in each cycle because the residual water not recovered in one cycle becomes a transition or buffer zone of marginal quality surrounding the stored water in the next cycle. Building the buffer zone around each ASR well is usually completed over a series of cycles, typically about three to six, at the end of which the ultimate recovery efficiency for the site is achieved.

One ASR cycle consists of three different operating phases: injection, storage, and subsequent recovery of potable water. During the first phase, water is injected into an aquifer when excess runoff or excess water supplies from a treatment plant are available for storage. During the second operating phase, potable water is stored in an aquifer. Storage times are typically diurnal, long-term (injected during wet years then recovered in dry years), or seasonal (injected during the fall and winter then recovered in the spring and summer). Water may also be stored for emergency use during drought or flooding. The last part of the cycle is recovery. Recovered water is used for drinking water, irrigation, and other agricultural purposes.

5. POTENTIAL AND DOCUMENTED DAMAGE TO USDWs

5.1 Injectate Constituent Properties

As discussed in Section 4.1, water injected into aquifers through the use of aquifer recharge and ASR wells is typically treated to meet primary and secondary drinking water standards. This is done to protect the host aquifer and to help ensure that the quality of the ground water to be recovered is adequate for subsequent use. In addition, treatment of the injectate in aquifer recharge and ASR wells to drinking water standards is required by most regulatory agencies in order to prevent degradation of ambient ground water quality (see Section 7). However, not all fluids injected into aquifer recharge and ASR wells meet drinking water standards. Injection of fluids with chemical concentrations can be allowed as long as it is found not to endanger USDWs. Thus, aquifer recharge and ASR wells injecting fluids that do not meet drinking water standards can still have an environmental benefit.

It should be noted that, even when water injected into aquifers through the use of aquifer recharge and ASR wells has been treated, a few constituents have been measured at concentrations slightly above drinking water standards. For example, fluoride concentrations in the recharge water used in the Huron Project in South Dakota (see Section 4.1.1) and combined radium 226 and 228 concentrations at Centennial Water and Sanitation District in Denver, Colorado (see Section 4.1.2) have been observed slightly above the drinking water standards.

5.2 Observed Impacts

The objective of aquifer recharge and ASR wells is to replenish water in an aquifer for subsequent use. Thus, aquifer recharge and ASR wells are closely controlled to make sure they safely augment the amount of water available from a USDW. These controls make hazardous material spills or illicit discharges into aquifer recharge and ASR wells unlikely.

Based on information obtained from state and USEPA Regional offices, there are no known contamination incidents associated with the use of aquifer recharge and ASR wells. However, changes in water quality of the aquifers have been observed. In addition, in some instances, injection of high quality water into aquifers that contain either brackish or poor quality water has improved the ambient ground water quality.

6. BEST MANAGEMENT PRACTICES

6.1 Aquifer Recharge and ASR Wells

6.1.1 Recharge Water Quality

In order to ensure the use of "good" quality recharge water, monitoring of recharge water quality should be performed on a routine basis. If the recharge water is not low in suspended solids, air, and microorganisms, and is not chemically compatible with natural ground water and the aquifer material, clogging can cause a recharge operation to be infeasible (Lichtler et al., 1980).

The intended use or recharge objective needs to be considered in evaluating the quality of the recharge water. For example, if artificial recharge is going to be used primarily for water storage, it is necessary to consider changes that may take place between the time of recharge and the time of withdrawal and use by the consumer. The following basic processes must be considered when evaluating water quality changes likely to occur during ground water recharge and storage:

1. biodegradation by and growth of microorganisms;
2. chemical oxidation or reduction;
3. sorption and ion exchange;
4. filtration;
5. chemical precipitation or dilution; and
6. volatization or photochemical reactions.

In addition, a contaminant source inventory in the area supplying the injectate water should be conducted in order to prevent potential contamination of the receiving aquifer.

6.1.2 Water Monitoring in Recharge Projects

Monitoring of ground water is necessary to ascertain the direction and rate of movement of water and the extent of water quality changes occurring during movement of the recharged water through the aquifer. As a result, a monitoring plan is needed to properly assess and minimize the water quality impacts of an aquifer recharge project. A monitoring plan should take into account several conditions, including:

- The nature of the hydrogeologic and hydrochemical setting;
- An analysis of the source of the recharge water;
- A determination of the constituents that may be contributed by the source; and
- An assessment of potential aquifer-plugging mechanisms (Shea-Albin, 1997).

Initially, ground water and recharge water should be monitored for all analytes for which drinking water standards have been promulgated and for all potential contaminants in the source water contribution area. It is important to analyze for all of these contaminants during the baseline sampling period, even if a particular aquifer may not be vulnerable to contamination. If contaminants of concern are not present in baseline samples, reduction in future monitoring requirements may be possible (Shea-Albin, 1997).

6.1.3 Physical, Biological, Chemical, and Mechanical Clogging

Understanding the interaction between the recharge and native water will prevent clogging of the well, which is one of the major operational problems with recharge injection wells. Factors that may contribute to clogging of the well include:

1. suspended sediment in the recharge water (including both organic and inorganic matter);
2. entrained air in the recharge water;
3. microbial growth in a well;
4. chemical reactions between recharge water and the native ground water, the aquifer material, or both;
5. ionic reactions that result in dispersion of clay particles and swelling of colloids in a sand-and-gravel aquifer;
6. iron precipitation;
7. biochemical changes in the recharge water and ground water involving iron-reducing bacteria or sulfate-reducing organisms; and
8. differences in temperature between recharge and aquifer water (Pyne 1995; Sniegocki, 1970).

The following sections describe the most common types of clogging problems and presents methods for the early detection and prevention of problems associated with physical, biological, chemical, and mechanical clogging problems.

Physical Clogging

Physical clogging problems result from suspended solids clogging the pores of the receiving formation, well screens, and/or gravel packs. This type of clogging is more prevalent in raw water recharge systems than in treated water systems because treated water will have few, if any, suspended solids. The particles settle around the recharge well, creating a need for higher injection pressures.

For ASR wells, backflushing, or reversing the flow of the wells for recovery operations, may alleviate physical clogging problems. The amount of time a well should be backflushed is site dependent. Some ASR wells are backflushed every day for 10 minutes to 2 hours, while others are backflushed every few weeks for varied durations. The waste from backflushing is sometimes routed to a water treatment plant for re-treatment before disposal to a drainage field, storm drain, dry well, pit, pond, or sewer system.

Physical clogging problems can also be the result of temperature differences between the injectate and the receiving waters. When cold injection water comes into contact with warm aquifer water, outgassing (formation of gas bubbles in the injectate) may occur. The dissolved gases in the injection water tend to escape out of solution and clog the aquifer. Outgassing due to temperature differentials may be prevented by studying the changes in water temperature and the mixing characteristics of the injectate and the receiving water (Pitt and Magenheimer, 1997). Cold water also tends to have a higher viscosity than warm water, which may reduce flow rates. The probability of clogging due to temperature differentials is highly site specific. Typically, temperature differentials are more likely to occur with the first injection cycle. The cold injectate displaces the receiving water around the borehole, and after the first injection cycle, little temperature difference is found.

Biological Clogging

Recharge wells are sometimes clogged by bacterial growth. Pre-chlorination of the injection water may solve the problem. For raw surface water or non-potable recharge systems, adding chlorine to the injection water will reduce well clogging.

Chemical Clogging

Chemical clogging problems can be caused by precipitates, clay colloids, gas bubbles, and protective chemicals (Pitt and Magenheimer, 1997). These problems may arise from geochemical reactions between native ground water and the injectate (Pitt and Magenheimer, 1997). For example, formation of chemical precipitates (usually calcium carbonate, calcium sulphate, iron oxides, manganese oxides, magnesium hydroxide, and silicates) may arise as a result of reactions between native ground water and recharge water. These precipitates can clog the well screen, the gravel pack, or the formation.

Carbonate precipitation can be controlled by lowering the pH of injection water. If extensive precipitation has already occurred, acidizing the well with a corrosion inhibitor dissolves the precipitates and prevents further corrosion of the steel casing. Injection of liquid and gaseous carbon dioxide through the packer into the well screen will also remediate clogging. In this process, the gas expands, forms carbonic acid, and then freezes in the well screen. After a few days, the particles dissolve and pH values decrease (Pitt and Magenheimer, 1997).

Thin clay layers in the storage zone may swell and plug the formations around the zone. Clay colloids (particles) may also break free, travel as suspended solids, and clog the pores of the receiving formation. Injection waters containing high sodium concentrations may exacerbate clogging by hydrating the clay, thereby causing the clay to swell, potentially clogging the well and the aquifer. Examining the well construction report and geological data will determine whether or not clogging problems from clay colloids or thin clay layers in the injection zone can be expected. Remedial measures include adding chemical stabilizers to the injection water to reduce clay swelling and treating the injection water to remove sodium.

Outgassing from the injection water may also cause well clogging. In this case, an analysis of dissolved gases in the injection water should determine the degree of gas saturation. If the concentration of dissolved gases in injection water is likely to cause a well clogging problem, the water can be treated with degasification through a stripping column.

Sometimes chemicals such as anti-scalants, which are added to the injectate to protect pipelines in the distribution system, precipitate and contribute to aquifer clogging. Through chemical reactions, these chemicals dissolve, loosen, and re-suspend sediments in the pipelines and encourage bacterial growth (Pitt and Magenheimer, 1997). Using anti-scalants that degrade during transport from the treatment plant to the injection well (e.g., zinc pyrophosphate) will decrease the potential for well and aquifer clogging. For example, zinc pyrophosphate will not loosen and re-suspend bacteria and other solids in the pipelines because it degrades during transport. Well clogging due to anti-scalant chemicals may also be averted by performing a complete investigation of the chemicals used in the water treatment process. Assessing the potential chemical reactions between recharge water, pipeline materials, and anti-scalant chemicals will alert recharge managers to potential well clogging problems, so that clogging may be avoided or treated before serious problems occur.

Mechanical Clogging

For ASR wells, there are some potential problems that may be caused by mechanical clogging. Mechanical clogging problems include air entrainment and formation particle jamming (Pitt and Magenheimer, 1997). Air entrainment, one type of air clogging, traps atmospheric air in the ASR well and in the storage zone during the storage cycle. This may occur when the injection water has a lower temperature than native ground water, clogging the aquifer. Sealing the annulus at the well head typically prevents air entrainment during ASR operations. Air entrainment can be tested by conducting a mechanical integrity test (Pyne, 1995). Air entrainment is not equivalent to outgassing, although temperature differentials may cause outgassing and add to aquifer clogging problems. Other common causes of air clogging include loose connections in piping, the use of inadequate pumps, cavitation of the injection pump (air in the pump), and high injection velocities. These problems may best be addressed by maintaining airtight pipelines and connections, using centrifugal pumps, and ensuring that injection velocities are kept at a level below that which causes turbulent flow. Pump cavitation should not occur during injection (Pitt and Magenheimer, 1997).

Aquifer jamming may result from particle displacement when water flow in the ASR system is reversed from the injection to the recovery cycle. This problem is only encountered in loosely consolidated aquifers and when the well is gravel-packed with gravel/particles of relatively uniform size. When the water flow is reversed, the particles are drawn back toward the well, and their packing is rearranged. This reduces water flow efficiency and has the same effect on the ASR system as particulate clogging. To remediate aquifer jamming, the wells may need to be redeveloped by surging and pumping methods or by acidizing. Pressure fracturing or explosive fracturing, where the aquifer is broken apart by extreme physical or explosive force, will also dislodge the jammed aquifer but may not be permitted in every state. Maintaining low velocities during the recovery cycle and ensuring that the screen and gravel pack match the aquifer materials can reduce the risk of aquifer jamming (Pitt and Magenheimer, 1997).

6.2 ASR Wells

6.2.1 Location and Spacing of ASR Wells and Impact on Static Ground Water Levels

The long-term and regional effects of ASR cycles need to be considered when configuring ASR systems. Therefore, developing optimal water basin management strategies is important (Dickenson, 1997). Background basin hydrology, including natural recharge sources and locations, pumping patterns, discharge areas, and the proposed storage area, should be examined. Spilling and overdraft patterns (patterns where the water table and/or aquifer level is too high or too low) in the proposed ASR area should be assessed so that ASR injection and recovery operations dampen extreme fluctuations in ground water levels, rather than exacerbate existing problems. Pyne (1995) suggests that ASR facilities be located near water treatment plants and at least 100 feet from existing or potential sources of contamination. He also points out that this siting criterion is a regulatory requirement in some states.

6.2.2 Operation and Maintenance Practices for ASR Wells

In order to successfully operate an ASR system, the following operation and maintenance practices, as described by Pyne (1995), are recommended:

- *Periodic change in operating mode*. This occurs typically two to four times per year as the system changes from recharge to recovery and back again.
- *Backflushing to waste during recharge*. This procedure is implemented at most ASR sites in order to maintain recharge capacity by purging from the well any solids that may have been carried into the well during recharge. Backflushing frequency varies from every day to every few years, depending on site-specific conditions. Some ASR wells currently in operation are redeveloped seasonally by extended pumping, as part of the recovery operation, without any additional backflushing frequency.

- *Trickle flow of chlorinated water*. During periods of storage, it is advisable to maintain a trickle flow of chlorinated water into the well. This will control bacterial activity in the formation immediately adjacent to the well, thereby helping to maintain recharge-specific capacity and bacterial clogging.

- *Calibration of pressure gauges, flow meters, chart recorders, and other equipment associated with the ASR well system*. It is important to accurately keep track of flow rates and pressure and water levels in order to determine whether clogging is occurring and backflushing is necessary.

- *Monitoring*. Monitoring of ground water during recharge, storage, and recovery is necessary to ascertain the direction and rate of movement of water and the extent of water quality changes occurring during movement of the recharged water through the aquifer.

- *Annual water accounting or water balance*. It is important to accurately track the volume of water stored and recovered from an ASR well system. If the volume of water recovered is greater than the volume of the water stored, there might be a reduction in the recovery efficiency around the well, as well as adverse impacts on water levels in surrounding areas. In addition, ASR permits are sometimes issued providing only for seasonal storage and recovery, so that annual volume recovered cannot exceed the volume stored in the same year (Pyne, 1995).

- *Periodic review of operating and water quality data*. This review is necessary in order to evaluate performance relative to expectations, and make adjustments, as appropriate. This is particularly important in the first two to five years of system operation, when the greatest changes in water levels and water quality will tend to occur and normal ranges for various parameters tend to be defined.

7. CURRENT REGULATORY REQUIREMENTS

Several federal, state, and local programs exist that either directly manage or regulate Class V aquifer recharge and ASR wells. On the federal level, management and regulation of these wells falls primarily under the UIC program authorized by the Safe Drinking Water Act (SDWA). Some states and localities have used these authorities, as well as their own authorities, to extend the controls in their areas to address concerns associated with aquifer recharge and ASR wells.

7.1 Federal Programs

7.1.1 SDWA

Class V wells are regulated under the authority of Part C of SDWA. Congress enacted the SDWA to ensure protection of the quality of drinking water in the United States, and Part C specifically mandates the regulation of underground injection of fluids through wells. USEPA has promulgated a series of UIC regulations under this authority. USEPA directly implements these regulations for Class V wells in 19 states or territories (Alaska, American Samoa, Arizona, California, Colorado, Hawaii, Indiana, Iowa, Kentucky, Michigan, Minnesota, Montana, New York, Pennsylvania, South Dakota, Tennessee, Virginia, Virgin Islands, and Washington, DC). USEPA also directly implements all Class V UIC programs on Tribal lands. In all other states, which are called Primacy States, state agencies implement the Class V UIC program, with primary enforcement responsibility.

Aquifer recharge and ASR wells currently are not subject to any specific regulations tailored just for them, but rather are subject to the UIC regulations that exist for all Class V wells. Under 40 CFR 144.12(a), owners or operators of all injection wells, including aquifer recharge and ASR wells, are prohibited from engaging in any injection activity that allows the movement of fluids containing any contaminant into USDWs, "if the presence of that contaminant may cause a violation of any primary drinking water regulation . . . or may otherwise adversely affect the health of persons."

Owners or operators of Class V wells are required to submit basic inventory information under 40 CFR 144.26. When the owner or operator submits inventory information and is operating the well such that a USDW is not endangered, the operation of the Class V well is authorized by rule. Moreover, under section 144.27, USEPA may require owners or operators of any Class V well, in USEPA-administered programs, to submit additional information deemed necessary to protect USDWs. Owners or operators who fail to submit the information required under sections 144.26 and 144.27 are prohibited from using their wells.

Sections 144.12(c) and (d) prescribe mandatory and discretionary actions to be taken by the UIC Program Director if a Class V well is not in compliance with section 144.12(a). Specifically, the Director must choose between requiring the injector to apply for an individual permit, ordering such action as closure of the well to prevent endangerment, or taking an enforcement action. Because aquifer recharge and ASR wells (like other kinds of Class V wells) are authorized by rule, they do not have to obtain a permit unless required to do so by the UIC Program Director under 40 CFR 144.25. Authorization by rule terminates upon the effective date of a permit issued or upon proper closure of the well.

Separate from the UIC program, the SDWA Amendments of 1996 establish a requirement for source water assessments. USEPA published guidance describing how the states should carry out a source water assessment program within the state's boundaries. The final guidance, entitled *Source Water Assessment and Programs Guidance* (USEPA 816-R-97-009), was released in August 1997.

State staff must conduct source water assessments that are comprised of three steps. First, state staff must delineate the boundaries of the assessment areas in the state from which one or more public drinking water systems receive supplies of drinking water. In delineating these areas, state staff must use "all reasonably available hydrogeologic information on the sources of the supply of drinking water in the state and the water flow, recharge, and discharge and any other reliable information as the state deems necessary to adequately determine such areas." Second, the state staff must identify contaminants of concern, and for those contaminants, they must inventory significant potential sources of contamination in delineated source water protection areas. Class V wells, including aquifer recharge and ASR wells, should be considered as part of this source inventory, if present in a given area. Third, the state staff must "determine the susceptibility of the public water systems in the delineated area to such contaminants." State staff should complete all of these steps by May 2003 according to the final guidance.[2]

7.1.2 Other Federal Rules and Programs

As stated earlier, aquifer recharge and ASR wells are used to replenish water in an aquifer. In most cases, aquifer recharge and ASR wells inject water into USDWs. Thus, the injectate from these wells is typically treated to drinking water standards established under Section 1412 of the SDWA. This section requires USEPA to establish National Primary Drinking Water Regulations for a contaminant if (1) the contaminant may have an adverse public health effect; (2) it is known or likely to occur in public water systems with a frequency and at levels of public health concern; and (3) if regulation of such contaminant presents a meaningful opportunity for health risk reduction. A brief description of these regulations follows.

Total Trihalomethane Rule

In November 1979, USEPA set an interim MCL for total trihalomethanes (TTHMs) of 0.10 mg/l as an annual average (44 FR 68624). Compliance is defined on the basis of a running average of quarterly averages of all samples. The value for each sample is the sum of the measured concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The interim TTHM standard only applies to community water systems using surface water and/or ground water serving at least 10,000 people that add a disinfectant to the drinking water during any part of the treatment process.

Surface Water Treatment Rule

In June 29, 1989, USEPA promulgated the final Surface Water Treatment Rule (SWTR) (54 FR 27486). Under the SWTR, USEPA set maximum contaminant level goals (MCLGs) of zero for *Giardia lamblia*, viruses, and *Legionella*; and promulgated NPDWRs for all public water systems using surface water sources or ground water sources under the direct influence of surface water. The SWTR includes treatment technique requirements for filtered and unfiltered systems that are intended to protect against the adverse health effects of exposure to *Giardia lamblia*, viruses, and *Legionella*, as well as many other pathogenic organisms. The rule became effective in June 1993.

Total Coliform Rule

In June 29, 1989, USEPA also promulgated the Total Coliform Rule, which applies to all public water systems (54 FR 27544). This regulation sets compliance with a MCL for total

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[2] May 2003 is the deadline including an 18-month extension.

coliforms. If a system exceeds the MCL, it must notify the public using mandatory language developed by the USEPA.

Interim Enhanced Surface Water Treatment

On December 16, 1998, USEPA finalized the Interim Enhanced Surface Water Treatment Rule (IESWTR) (63 FR 69478). The purposes of the IESWTR are to: (1) improve control of microbial pathogens, including specifically protozoan *Cryptosporidium*, in drinking water; and (2) address risk trade-offs with disinfection products. The IESWTR applies to public water systems that use surface or ground water under the direct influence of surface water and serve 10,000 or more people. The regulation became effective on February 16, 1999.

Stage 1 Disinfection Byproducts Rule

In December 16, 1998, USEPA finalized: (1) maximum residual disinfectant level goals (MRDLGs) for chlorine, chloramines, and chlorine dioxide; (2) MCLGs for four trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform), two haloacetic acids (dichloroacetic acid and trichloroacetic acid), bromate, and chlorite; and (3) NPDWRs for three disinfectants (chlorine, chloramines, and chlorine dioxide), two groups of organic disinfection byproducts (TTHMs—a sum of chloroform, bromodichloromethane, dibromochloromethane, and bromoform—and haloacetic acids—a sum of dichloroacetic acid, trichloroacetic acid, monochloroacetic acid, and mono-and dibromoacetic acids), and two inorganic disinfection byproducts (chlorite and bromate) (63 FR 69389). The NPDWRs consist of maximum residual disinfectant levels or MCLs or treatment techniques for these disinfectants and their byproducts. The NPDWRs also include monitoring, reporting, and public notification requirements for these compounds.

The Stage 1 Disinfection Byproducts Rule applies to public water systems that are community water systems and nontransient, noncommunity water systems that treat their water with a chemical disinfectant for either primary or residual treatment. In addition, certain requirements for chlorine dioxide apply to transient noncommunity water systems.

Radon Rule

On July 18, 1991, USEPA proposed a MCLG, a MCL, monitoring, reporting, and public notification requirements for radon and a number of other radionuclides in public water supplies (systems serving 25 or more individuals or with 15 or more connections) (56 FR 33050). USEPA proposed to regulate radon at 300 pCi/l.

On August 6, 1996, Congress passed amendments to the SDWA. Section 1412(b)(13)(A) of the SDWA, as amended, directs USEPA to withdraw the proposed national primary drinking water regulation for radon. Thus, as directed by Congress, on August 6, 1997 (62 FR 42221), USEPA withdrew the 1991 proposed MCLG, MCL, monitoring, reporting, and public notification requirements for radon.

USEPA expects to publish a final MCLG and national primary drinking water regulation for radon by August, 2000.

Ground Water Rule

Currently, USEPA is developing a Ground Water Rule that will specify appropriate use of disinfection and encourage the use of alternative approaches, including best management practices and control of contamination at its source. The rule will be designed to protect against pathogenic bacteria and viruses in source water, against growth of opportunistic pathogenic bacteria in ground water distribution systems, and to mitigate against any failure in the engineered systems, such as cross-connections or sewage infiltration into distribution systems. The Ground Water Rule will apply to systems using only ground water, which are not regulated under the 1989 SWTR.

USEPA expects to publish the Final Ground Water Rule by November 2000. The statutory deadline, under the SDWA (Section 1412(b)(8)), for the Ground Water Rule is May 2002.

7.2 State and Local Programs

The requirements pertaining to aquifer recharge and ASR wells in states that contain substantial numbers of such wells are sometimes identical. In California, for example, both types of wells are regulated under the state's Water Quality Control Act. Florida, in contrast, has enacted specific regulatory requirements for aquifer storage and recovery. Some relatively arid western states have enacted rules pertaining to aquifer storage and recovery as part of their system of regulating the use of the water resources of the state, but those requirements also may touch upon well construction standards and/or monitoring requirements.

This section summarizes the existing UIC programs in the states where the vast majority of the aquifer recharge and ASR wells are known to exist: California, Colorado, Florida, Idaho, Nevada, Oklahoma, Oregon, South Carolina, Texas, and Washington (see Section 3). Altogether, these ten states have a total of 1,049 documented aquifer recharge and ASR wells, which is approximately 89 percent of the documented well inventory for the nation. More detail on these state programs is provided in Attachment C of this volume.

It should be noted that ASR wells are not specifically defined in 40 CFR Part 146. Thus, the definition of ASR wells may vary from state to state.

In California, USEPA Region 9 directly implements the UIC program for Class V injection wells. Aquifer recharge and ASR wells in the state are authorized by rule in accordance with the existing federal requirements. However, if treated wastewater is planned to be used for artificial recharge, Regional Water Quality Control Boards issue site-specific discharge requirements. In addition, the Department of Health Services must review and approve the application. The injectate must meet drinking water standards at the point of injection. County water districts and/or county health departments may supplement the requirements. If potable water is planned to be used for aquifer recharge, the projects are reviewed and regulated by local health departments.

In Colorado, USEPA Region 8 directly implements the UIC program for Class V injection wells. The state does not have rules explicitly addressing ASR wells, but it has enacted requirements directly addressing artificial recharge. However, those rules apply primarily to the permitting of extraction and use of waters artificially recharged. The rules do provide that water artificially recharged into a Denver Basin aquifer, whether for the maintenance of water levels or for subsequent extraction, shall be, at the time of extraction, fully consumable and/or reusable (Rule 5.1). In addition, the State Engineer accounts for water that is artificially recharged and administers the orderly withdrawal of such water to prevent injury to existing water users and water rights holders.

Florida is a UIC Primacy State for Class V wells. In this state, owners or operators of aquifer recharge and ASR wells are required to obtain a Construction/Clearance Permit from the Department of Environmental Protection before receiving permission to construct. In order to use the well, the applicant is required to submit information needed to demonstrate that well operation will not adversely affect a USDW. Once such a demonstration is made, the Department will issue an authorization to use the well subject to certain operating and reporting requirements, including the requirement to meet drinking water standards at the point of injection. Injection of fluids that exceed the drinking water standards is allowed only if it is not into a USDW and if it is controlled in accordance with a site-specific operating permit.

Idaho is a UIC Primacy State for Class V wells. In this state, construction and operation of shallow injection wells (<18 feet) is authorized by rule, as long as inventory information is provided and use of the well does not result in endangerment of a drinking water source or cause a violation of state water quality standards that would affect beneficial use. Construction and use of a deep injection well ($18 feet) requires an individual permit.

Nevada is a UIC Primacy State for Class V wells. In this state, construction and operation of aquifer recharge and ASR wells are prohibited except as authorized by permit by the State Engineer. The State Engineer must determine that the project is hydrologically feasible and that it will not cause harm to users of land or other water within the area of hydrological effect of the project. The permit specifies the capacity and plan of operation of the recharge project, any required monitoring, and any other conditions believed necessary to protect ground water.

Oklahoma is a UIC Primacy State for Class V wells. The state has incorporated by reference into the Oklahoma Administrative Code those parts of 40 CFR Part 124 and Parts 144 to 148 that apply to the UIC program (252-652-1-3 OAC). Thus, aquifer recharge and ASR wells in the state are authorized by rule in accordance with the existing federal requirements.

Oregon is a Primacy State for UIC Class V wells. In this state, the UIC program is administered by the Department of Environmental Quality. However, the Oregon Administrative Rules (OAR) contain special provisions administered by the Water Resources Department addressing ASR and artificial ground water recharge (OAR 690 Division 350). OAR requires a limited license for ASR testing before a permanent ASR permit may be obtained (690-350-0010(2) OAR). The injection source water for ASR is required to comply with drinking water standards, treatment requirements, and performance standards established by the state Health Department or maximum measurable levels established by the Environmental Quality Commission, whichever are more stringent. No license or permit may establish concentration limits for water to be injected for ASR in excess of standards established by the Health Department or the Environmental Quality Commission (690-350-0010(6)(a)-(c) OAR). Use of artificially recharged waters requires a secondary ground water permit specifying the maximum diversion rate and volume of withdrawals and allowable uses of stored recharged water (690-350-0130 OAR).

South Carolina is a UIC Primacy State for Class V wells. In this state, aquifer recharge and ASR wells are prohibited except as authorized by permit. Injection may not commence until construction is complete, the permittee has submitted notice of completion to the Department of Health and Environmental Control (DHEC), and DHEC has inspected the well and found it in compliance. DHEC will establish maximum injection volumes and pressures and other such permit conditions as necessary to assure that fractures are not initiated in the confining zone adjacent to the USDW and to assure compliance with operating requirements. The movement of injected fluids containing contaminants into USDWs is prohibited if the contaminant may cause a violation of any drinking water standard or otherwise adversely affect health.

Texas is a UIC Primacy State for Class V wells. In this state, underground injection is prohibited, unless authorized by permit or rule. By rule, injection into an aquifer recharge well is authorized , although the Texas Natural Resources Control Commission may require the owner or operator of a well authorized by rule to apply for and obtain an injection well permit. No permit or authorization by rule is allowed where an injection well causes or allows the movement of fluid that would result in the pollution of a USDW.

Washington is a UIC Primacy State for Class V wells. In this state, an individual permit is required to operate an aquifer recharge or ASR well. In addition, Washington has set standards for direct ground water recharge projects using reclaimed water. These rules primarily address the standards and treatment requirements for the reclaimed water, when injected into potable and non-potable ground water.

Although an ASR well exist in Tennessee, the Tennessee Department of Environment and Conservation (TDEC), Division of Water Supply, regulates this well as a Class V UIC experimental well. The TDEC indicated that this injection well was permitted as an experimental well because, although aquifer storage and retrieval system technology had been demonstrated in other states, this is the first such system to be constructed in Tennessee (TDEC, 1996a; TDEC, 1996b). TDEC issued the permit to the MLGWD in 1996 (TDEC, 1996c). This permit expires in 2001. The MLGWD is permitted to inject no more than 600 gallons per minute of treated drinking water into the ASR system at a maximum injection pressure of 125 psi. The MLGWD is also required to conduct injectate sampling and analysis for injectate quality at the start up of each injectate event.

ATTACHMENT A
ASR WELL DATA REPORTED IN LITERATURE

Location	Operational Information	Storage Zone	Number of ASR Wells	Data Source
Brick, NJ	Began operations in 1996.	N/A	1	Horvath, 1997
Gordon's Corner, NJ	Began operations in 1972.	Clayey sand	2	Pyne, 1995
Murray Avenue, NJ	Began operations in 1994.	Clayey sand	2	Pyne, 1995
Swimming River, NJ	Began operations in 1993. Injection into aquifer with high iron concentration due to siderite and pyrite.	Clayey sand	1	Pyne, 1995
Wildwood, NJ	Began operations in 1968. Also beneficial for preventing saltwater intrusion.	Sand (Cohansey aquifer)	4	Amans and McLeod, 1991; Horvath, 1997; Lacombe, 1997; Pyne, 1995
Chesapeake, VA	Began operations in 1990.	Sand	1	Horvath, 1997; Pyne, 1995
Boynton Beach, FL	Began operations in 1993. Injection into brackish aquifer.	Limestone	1 (1 additional well expected)	Pyne, 1995
Cocoa, FL	Began operations in 1987. Injection into brackish aquifer.	Limestone	6 wells, plans for 4 more wells	Pyne, 1995
Collier County, FL	Began operations in August 1998. Injection into brackish aquifer.	Limestone (Hawthorne Zone II Aquifer)	1	Walker, 1999
Hillsborough County, FL	Operational testing is expected in 1998 and 1999. Injection into a brackish aquifer.	Limestone (lower Suwanee Limestone)	1 test well to be installed (Construction to be complete by December, 1997)	McNeal et al., 1997
Manatee, FL	Began operations in 1983. Injection into brackish aquifer.	Limestone	1	Pyne, 1995
Marathon, FL	Began operations in 1994. Injection into a saline aquifer.	Sand	1 test well, plans for 7 more wells	Pyne, 1995
Marco Island, FL	Injection into a brackish aquifer.	Limestone	1 test well	Horvath et al., 1997
Peace River, FL	Began operations in 1985. Injection into brackish aquifer.	Limestone	9	Horvath, 1997; Pyne, 1995; Singer et al., 1993; Southwest Florida Water Management District, website
Port Malabar, FL	Began operations in 1989. Injection into brackish aquifer.	Limestone	1	Pyne, 1995
Tampa, FL	Permit had been granted, but construction had not yet begun in 1997.	N/A	1	Deuerling, 1997

ATTACHMENT A
ASR WELL DATA REPORTED IN LITERATURE (continued)

Location	Operational Information	Storage Zone	Number of ASR Wells	Data Source
Kerrville, TX	Began operations in 1991.	Sandstone (Hosston-Sligo formation in the Lower Trinity Aquifer)	2	Amans and McLeod, 1988; Amans and McLeod, 1991; Pyne, 1995; Singer et al., 1993
Ankeny, IA	Part of a research and demonstration project. Injection into a poor quality aquifer (slightly brackish).	Sandstone (Jordon aquifer)	1 test well	Miller and Beavers, 1997
Wichita, KS	Research and demonstration project jointly sponsored by the city of Wichita and the USGS to determine water-quality effects of ASR on ground water.	Equus beds wellfield	N/A	United States Geological Survey, website
Highlands Ranch, CO	Began operations in 1993.	Sand	1 well, 2 more expected	Pyne, 1995; Singer et al., 1993
Calleguas, CA	Began operations in 1992. Electricity generation during recharge periods.	Sand (North Las Posas Ground Water Basin)	1 well, 4 more expected by end of 1997, investigating sites for 25 more wells	Breault, 1997; Calleguas Municipal Water District, website; Pyne, 1995
Goleta, CA	Began operations in 1978. All wells were retrofitted for ASR and recharge purposes. Recharge occurred in only seven years between 1978 and 1988.	Silty, clayey sand	9	Pyne, 1995
Lancaster, CA	One test well operated in 1994, one other well currently in test phase.	(Lancaster Aquifer)	2	Antelope Valley Board of Trade, website
Oxnard, CA	Began operations in 1989.	Alluvial aquifer overlain by thick, areally extensive clay deposits (Oxnard Aquifer)	5	City of Oxnard, 1996; Pyne, 1995
Pasadena, CA	Began operations in 1992. Considering electricity generation during recharge.	Sand (Raymond Ground Water Basin)	2	Pyne, 1995
Salem, OR	Pilot ASR well program undertaken in 1994/1995.	Basalt	4	Eckley, 1999
Seattle, WA	Began operations in 1992.	Glacial drift	3	Pyne, 1995

N/A Not available.

ATTACHMENT B
ASR FACILITIES AND WELLS IN FLORIDA

Updated: 12/07/98

Facility Name	ASR Type*	Map #	Pre-Application	Construction Application Received	Construction Permit Issued	Well Constructed	Operational Testing	Operation Permit
Boynton Beach ASR	TDW	14					X	
Broward County 2A WTP	RGW	15					X	
Miami-Dade Southwest Wellfield	RGW	17				X		
Miami-Dade West Wellfield	RGW	18				X		
Deerfield Beach ASR	TDW	16		X				
Fiveash WTP	TDW future RGW	24				X		
Miami Beach ASR	TDW	21					X	
Taylor Creek ASR	RSW	12					X (not used)	
West Palm Beach ASR	TDW interim PTS future RSW	13					X	
Peace River Wells 1-9 Wells 10-21	TDW	5		X				X
Palm Beach County System #3	TDW future RGW	22				X		
Delray Beach	TDW	26		X		X (WMD permit)		
Collier County	TDW	8						X
FKAA Marathon	TDW	19					X(not used)	
Corkscrew (Lee County) Well #1 Wells 2-6	TDW	6	X			X		
Marco Lakes Well #1 Wells 2-9	PTS	7		X			X	
Punta Gorda	TDW	23				X		
San Carlos Estates (Bonita Springs Utilities)	TDW	29		X				
Kehl Canal (Bonita Springs Utilities)	PTS	30		X				
Fort Myers	TDW	31		X				
North Reservoir (N. Ft. Myers)	TDW	33	X					

ATTACHMENT B
ASR FACILITIES AND WELLS IN FLORIDA (continued)

Facility Name	ASR Type*	Map #	Pre-Application	Construction Application Received	Construction Permit Issued	Well Constructed	Operational Testing	Operation Permit
Olga	RSW	34	X					
Tampa - Rome Avenue Well #1 Wells 2-9	TDW	1		X				X
Tampa - Hillsborough River	PTS	2		X				
Lake Manatee Wells B-1 and B-2 Wells B-3 through B-6	TDW	4		X				X
Cocoa - Claude H. Dyal Wells 1-6 Wells 6-10	TDW	9				X		X
Palm Bay	TDW	11						X
Sunrise Springtree	TDW	20				X		

*ASR Types:

TDW Potable through drinking water plant.
RSW Raw surface water.
RGW Raw ground water.
PTS Partially treated surface water.

ATTACHMENT C
STATE AND LOCAL PROGRAM DESCRIPTIONS

This attachment does not describe every state's regulatory requirements; instead, it focuses on the ten states where aquifer recharge and ASR wells are known to exist: California, Colorado, Florida, Idaho, Nevada, Oklahoma, Oregon, South Carolina, Texas, and Washington. Altogether, these ten states have a total of 1,051 documented aquifer recharge and ASR wells, which is approximately 87 percent of the documented well inventory for the nation.

California

USEPA Region 9 directly implements the UIC program for Class V injection wells in California. The California Water Quality Control Act (WQCA), however, establishes broad requirements for the coordination and control of water quality in the state, sets up a State Water Quality Control Board, and divides the state into nine regions, with Regional Water Quality Control Boards (RWQCBs) that are delegated responsibilities and authorities to coordinate and advance water quality in each region (Chapter 4 Article 2 WQCA). A RWQCB can prescribe requirements for discharges (waste discharge requirements, or WDRs) into the waters of the state (13263 WQCA). These WDRs can apply to injection wells (13263.5 and 13264(b)(3) WQCA). In addition, the WQCA specifies that no provision of the Act or ruling of the State Board or a Regional Board is a limitation on the power of a city or county to adopt and enforce additional regulations imposing further conditions, restrictions, or limitations with respect to the disposal of waste or any other activity which might degrade the quality of the waters of the state (13002 WQCA).

Permitting

The WQCA provides that any person operating, or proposing to operate, an injection well (as defined in §13051 WQCA) must file a report of the discharge, containing the information required by the Regional Board, with the appropriate Regional Board (13260(a)(3) WQCA). Furthermore, the RWQCB, after any necessary hearing, may prescribe requirements concerning the nature of any proposed discharge, existing discharge, or material change in an existing discharge to implement any relevant regional water quality control plans. The requirements also must take into account the beneficial uses to be protected, the water quality objectives reasonably required for that purpose, other waste discharges, and the factors that the WQCA requires the Regional Boards to take into account in developing water quality objectives, which are specified in §13241 of the WQCA (13263(a) WQCA). However, a RWQCB may waive the requirements in 13260(a) and 13253(a) as to a specific discharge or a specific type of discharge where the waiver is not against the public interest (13269(a) WQCA).

If treated wastewater is planned to be used for aquifer recharge, the approach followed by RWQCBs is to issue site-specific WDRs. In addition, the Department of Health Services must review and approve the application. The recharge injectate must meet drinking water MCLs at the point of injection. County water districts and/or county health departments may supplement the requirements. If potable water is planned to be used for aquifer recharge, the projects are reviewed and regulated by health departments.

Siting and Construction Requirements

Department of Water Resources Bulletin 74-90 provides specifications for well construction standards.

Operating Requirements

Not specified by statute or regulations.

Monitoring Requirements

Not specified by statute or regulations.

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

Not specified by statute or regulations.

Colorado

USEPA Region 8 directly implements the UIC program for Class V injection wells in Colorado. The State of Colorado does not have rules explicitly addressing aquifer storage and recovery, but it has enacted requirements directly addressing artificial recharge. However, those rules apply primarily to the permitting of extraction and use of waters artificially recharged (Rules and Regulations for the Permitting and Use of Waters Artificially Recharged into the Dawson, Arapahoe, and Laramie-Fox Hills Aquifers, 2 Colorado Code of Regulations (CCR) 402-11). The rules do provide that water artificially recharged into a Denver Basin aquifer, whether for the maintenance of water levels or for subsequent extraction, shall be, at the time of extraction, fully consumable and/or reusable (Rule 5.1).

Permitting

Permitting requirements under the artificial recharge rules apply only to extraction. However, an application to construct a well to extract artificially recharged water must include information about whether the aquifer is confined or unconfined at the injection site(s) and other information concerning the aquifer at and around the well or wells through which the water was injected, including an accounting of the timing, amount, and location(s) of injection of artificially recharged water which is to be extracted through the proposed well (Rule 6.3.1).

Like almost all western states, Colorado issues permits for the extraction and use of both surface water and ground water. Permits for extraction and use must consider impacts to existing wells and other water rights. The rules on permitting and use of waters artificially recharged into the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers define extraction well as an existing permitted well or a well that has been, or will be constructed, for the purpose of extracting artificially recharged water. When applied to an existing permitted well, this term may describe a well which has been authorized for the extraction of an amount of water beyond the amount of naturally occurring ground water authorized for withdrawal under the existing permit (Rule 4.3.8). Use of totalizing flow meters is required for measuring the amount of all water injected and extracted (Rule 5.7.1). The State Engineer accounts for water that is artificially recharged and administers the orderly withdrawal of such water to prevent injury to existing water users and water rights holders.

Siting and Construction Requirements

Colorado's water well construction rules (2. CCR 402-2) do not state explicitly that they apply to artificial recharge wells, but because they apply to the construction of water wells, the state applies them. A permit issued by the State Engineer is required prior to constructing a new or replacement well (Water Well Construction Rule 6).

Siting and construction requirements under the artificial recharge rules apply only to extraction. The water well construction rules contain detailed requirements concerning well location and minimum well construction standards (Rule 10). They include specifications for well casing, sealing and grouting, and disinfection (Rule 10.4 - 10.9 and Rule 17).

Operating Requirements

The wells used for artificial recharge and/or extraction are required to have totalizing flow meters installed to measure the amount of all water injected and extracted (Rule 5.7). If the meter is not operational, the well may not be operated.

Monitoring Requirements

Not specified by statute or regulations.

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

Not specified by statute or regulations.

Florida

Florida is a UIC Primacy State for Class V wells. Chapter 62-528 of the Florida Administrative Code (FAC), effective June 24, 1997, establishes the state's UIC program, and Part V of Chapter 62-528 (62-528.600 to 62-528.900) addresses criteria and standards for Class V wells. Class V wells are grouped for purposes of permitting into eight categories. Aquifer recharge wells fall into Group 2. Wells associated with an aquifer storage and recovery system fall into Group 7.

Permitting

Underground injection through a Class V well is prohibited except as authorized by permit by the Department of Environmental Protection. Owners and operators are required to obtain a Construction/Clearance Permit before receiving permission to construct. The applicant is required to submit detailed information, including well location and depth, description of the injection system and of the proposed injectate, and any proposed pretreatment. When site-specific conditions indicate a threat to a USDW, additional information must be submitted. The state generally issues letters of authorization, even when potable water is injected and no permit is required. The letter of authorization can include specific conditions with respect to the standards that must be met by the injected water, monitoring requirements for flow rate and pressure, sampling of monitoring well, and reporting. Finally, all Class V wells are required to obtain a plugging and abandonment permit.

In addition, local Water Management Districts and/or County Environmental Management Departments also review applications for aquifer storage and recovery wells.

Siting and Construction Requirements

Specific construction standards for Class V wells have not been enacted by Florida, because of the variety of Class V wells and their uses. Instead, the state requires the well to be designed and constructed for its intended use, in accordance with good engineering practices, and approves the design and construction through a permit. The state can apply any of the criteria for Class I wells to the permitting of Class V wells, if it determines that without such criteria the Class V well may cause or allow fluids to migrate into a USDW and cause a violation of the state’s primary or secondary drinking water standards, which are contained in Chapter 62-550 of the FAC. However, if the injectate meets the primary and secondary drinking water quality standards and the minimum criteria contained in Rule 62-520-400 of the FAC, Class I injection well permitting standards will not be required.

Class V wells are required to be constructed so that their intended use does not violate the water quality standards in Chapter 62-520 FAC at the point of discharge, provided that the drinking water standards of 40 CFR Part 142 (1994) are met at the point of discharge.

Operating Requirements

All Class V wells are required to be used or operated in such a manner that does not present a hazard to a USDW. Pretreatment of injectate must be performed, if necessary to ensure the fluid does not violate the applicable water quality standards in 62-520 FAC.

Monitoring Requirements

Monitoring generally will be required for Group 2 and 7 wells, unless the wells inject fluids that meet the primary and secondary drinking water standards in 62-550 FAC and the minimum criteria in Rule 62-520, and the injection fluids have been processed through a permitted drinking water treatment facility (62-528.615 (1)(a)2 FAC). Monitoring frequency will be based on well location and the nature of the injectate and will be addressed in the permit.

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

The owner or operator of any Class V well must apply for a plugging and abandonment permit when the well is no longer used or usable for its intended purpose. Plugging must be performed by a licensed water well contractor.

Idaho

Idaho is a UIC Primacy State for Class V wells and has promulgated regulations for the UIC Program in the Idaho Administrative Code (IDAPA), Title 3, Chapter 3. Deep injection wells are defined as more than 18 feet in vertical depth below the land surface (37.03.03.010.11 IDAPA). Wells are further classified, with Class V Subclass 5R21 defined as aquifer recharge wells (37.03.03.025.01.m IDAPA).

Permitting

Construction and use of shallow injection wells is authorized by rule, provided that inventory information is provided and use of the well does not result in unreasonable contamination of a drinking water source or cause a violation of the state's water quality standards that would affect a beneficial use (37.03.03.025.03.d. IDAPA). Construction and use of Class V deep injection wells is authorized by permit (37.03.03.025.03.c IDAPA). The regulations outline detailed specifications for the information that must be supplied in a permit application (37.03.03.035 IDAPA).

Operating Requirements

Standards for the quality of injected fluids and criteria for location and use are established for rule-authorized wells, as well as for wells requiring permits. The rules are based on the premise that if the injected fluids meet MCLs for drinking water for physical, chemical, and radiological contaminants at the wellhead, and if ground water produced from adjacent points of diversion for beneficial use meets the water quality standards found in Idaho's "Water Quality Standards and Wastewater Treatment Requirements," 16.01.02 IDAPA, administered by the Idaho Department of Health and Welfare, the aquifer will be protected from unreasonable contamination. State officials may, when it is deemed necessary, require specific injection wells to be constructed and operated in compliance with additional requirements (37.03.03.050.01 IDAPA (Rule 50)). Rule-authorized wells "shall conform to the drinking water standards at the point of injection and not cause any water quality standards to be violated at the point of beneficial use" (37.03.03.050.04.d IDAPA).

Monitoring Requirements

Monitoring, record keeping, and reporting may be required if state officials find that the well may adversely affect a drinking water source or is injecting a contaminant that could have an unacceptable effect upon the quality of the ground waters of the state (37.03.03.055 IDAPA (Rule 55)).

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

There are no financial responsibility requirements for rule-authorized wells. Permitted wells are required by the permit rule to demonstrate financial responsibility through a performance bond or other appropriate means to abandon the injection well according to the conditions of the permit (37.03.03.35.03.e IDAPA).

Plugging and Abandonment

The Idaho Department of Water Resources (IDWR) has prepared "General Guidelines for Abandonment of Injection Wells," which are not included in the regulatory requirements. IDWR expects to approve the final abandonment procedure for each well. The General Guidelines recommend the following:

- Pull the casing, if possible. If the casing is not pulled, cut the casing a minimum of two feet below the land surface.

- The total depth of the well should be measured.

- If the casing is left in place, it should be perforated and neat cement with up to 5 percent bentonite can be pressure-grouted to fill the hole. As an alternative, when the casing is not pulled, course bentonite chips or pellets may be used. If the well extends into the aquifer, the chips or pellets must be run over a screen to prevent any dust from entering the hole. No dust is allowed to enter the bore hole because of the potential for bridging. Perforation of the casing is not required under this alternative.

- If the well extends into the aquifer, a clean pit-run gravel or road mix may be used to fill the bore up to ten feet below the top of the saturated zone or ten feet below the bottom of casing, whichever is deeper, and cement grout or bentonite clay used to the surface. The use of gravel may not be allowed if the lithology is undetermined or unsuitable.

- A cement cap should be placed at the top of the casing if it is not pulled, with a minimum of two feet of soil overlying the filled hole/cap.

- Abandonment of the well must be witnessed by an IDWR representative.

Nevada

Nevada is a UIC Primacy State for Class V wells in which the Division of Environmental Protection (DEP) administers the UIC Program. In addition, the State Engineer is authorized to regulate the use of underground water, and projects for recharge and storage and recovery fall under that jurisdiction.

Nevada Revised Statutes (NRS) §§ 445A.300 - 445A.730 and regulations under the Nevada Administrative Code (NAC) §§ 445A.810 - 445A.925 establish the state's basic UIC Program. The injection of fluids through a well into any waters of the state, including underground waters, is prohibited without a permit issued by DEP (445A.465 NRS), although the statute allows both general and individual permits (445A.475 NRS and 445A.480 NRS). Furthermore, injection of a fluid that degrades the physical, chemical, or biological quality of the aquifer into which it is injected is prohibited, unless the DEP exempts the aquifer and the federal USEPA does not disapprove the exemption within 45 days after notice of it (445A.850 NRS). Regulations, particularly Chapter 445A NAC, "Underground Injection Control," define and elaborate these statutory requirements.

In addition, Chapter 534 of the Nevada Revised Statutes, "Underground Water and Wells" addresses recharge and storage and recovery activities.

Permitting

The UIC regulations specify detailed information that must be provided in support of permit applications, including proposed well location, description of geology, construction plans, proposed operating data on rates and pressures of injection, analysis of injectate, analysis of fluid in the receiving formation, proposed injection procedures, and corrective action plan (445A.867 NAC). The DEP may, however, modify the permit application information required for a Class V well.

The underground water statute provides that the State Engineer will supervise all wells tapping artesian water or water in definable underground aquifers, except wells for domestic purposes that do not require a permit (534.030.4 NRS). The State Engineer may establish a ground water basin water board to advise on approval of applications to issue permits to drill wells or take related actions (534.035 NRS). Persons seeking to sink or bore a well in any basin or portion thereof in the state designated by the State Engineer must first obtain a permit from the State Engineer (534.050 NRS). The statute also provides that any person seeking to operate a project for recharge, storage, and recovery of water must obtain a permit from the State Engineer. The State Engineer must determine that the project is hydrologically feasible and that it will not cause harm to users of land or other water within the area of hydrological effect of the project (534.250 NRS). A permit application must supply detailed information about the project, including the following:

- Evidence of financial and technical capacity;
- The source, quality and annual quantity of water proposed to be recharged, and the quality of the receiving water; and
- A study that demonstrates the area of hydrological effect of the project, that the project is hydrologically feasible, that the project will not cause harm to users of land and water within the area of hydrological effect; the percent of recoverable water.

The permit will specify the capacity and plan of operation of the project, any required monitoring, and any conditions (534.270 NRS).

Siting and Construction Requirements

The State of Nevada specifies that all injection wells must be situated on a well-drained site not subject to inundation by a 100-year flood and sited in such a way that the well injects into a formation that is separated from any USDW by a confining zone that is free of known open faults or fractures within the area of review. It must be cased from the finished surface to the top of the zone for injection and cemented to prevent movement of fluids into or between USDWs. All injections must be through tubing set on a mechanical packer and the packer must be set between the top of the zone for injection and the bottom of the next highest USDW and as close as possible to the top of the injected interval (445A.908 NAC).

Operating Requirements

Injection of a fluid that degrades the physical, chemical, or biological quality of the aquifer into which it is injected is prohibited, unless the DEP exempts the aquifer and the USEPA does not disapprove the exemption within 45 days after notice of it (445A.850 NRS).

Monitoring Requirements

Monitoring frequency for injection pressure, pressure of the annular space, rate of flow, and volume of injected fluid is specified by the permit for Class V wells. Analysis of injected fluid must be conducted with sufficient frequency to yield representative data. Mechanical integrity testing is required once each 5 years, by a specified method (445A.916 NAC).

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

A bond is required in favor of the state for the costs of plugging and abandonment of the well, except that the bond may be waived for Class V wells upon adequate proof of financial responsibility (445A.871 NAC).

Plugging and Abandonment

A plugging and abandonment plan and cost estimate must be prepared for each well, and reviewed annually. Before abandonment, a well must be plugged with cement in a manner that will not allow the movement of fluids into or between USDWs (445A.923 NAC).

Oklahoma

Oklahoma is a UIC Primacy State for Class V wells. The state has incorporated by reference into the Oklahoma Administrative Code (OAC) those parts of 40 CFR Part 124, and Parts 144 to 148 that apply to the UIC program (252-652-1-3 OAC).

Permitting

Applicants for Class V injection well facilities are required to perform ground water monitoring, provide an analysis of injected fluids and a description of the geologic strata through which and into which injection is taking place, and provide any addition information that the applicant believes is necessary to comply with 40 CFR 144.12 (252:652-5-3 OAC).

Siting and Construction Requirements

Not specified by statute or regulations.

Operating Requirements

Not specified by statute or regulations.

Monitoring Requirements

Not specified by statute or regulations.

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

Not specified by statute or regulations.

Oregon

Oregon is a Primacy State for UIC Class V wells. The UIC program is administered by the Department of Environmental Quality (DEQ). Under the State's Administrative Rules (OAR) pertaining to underground injection, "underground injection activity" means any activity involving underground injection of fluids, including waste disposal wells and ground water recharge wells. A "waste disposal well" is defined as any bored, drilled, driven or dug hole, whose depth is greater than its largest surface dimension, which is used or is intended to be used for disposal of sewage, industrial, agricultural, or other wastes and includes drain holes, drywells, cesspools and seepage pits, along with other underground injection wells (340-044-0005(22) OAR). Construction and operation of a waste disposal well is prohibited without a water pollution control facility (WPCF) permit. Certain categories of wells are prohibited entirely. Wells used for underground injection activities that allow the movement of fluids into a USDW if such fluids may cause a violation of any primary drinking water regulation or otherwise create a public health hazard or have the potential to cause significant degradation of public waters are prohibited (340-044-0015(4)(d) OAR). The rules also provide that any underground injection activity which may cause, or tend to cause, pollution of ground water may be approved by DEQ in addition to other permits or approvals required by other federal, state, or local agencies.

OAR contain special provisions administered by the Water Resources Department addressing ASR and artificial ground water recharge (OAR 690 Division 350). ASR is defined as the storage of water from a separate source that meets drinking water standards in a suitable aquifer for later recovery and not having as one of its primary purposes the restoration of the aquifer (690-350-0010(1)(a) OAR). Artificial ground water recharge is defined as the intentional addition of water diverted from another source to a ground water reservoir (690-350-0110(1) OAR).

Permitting

ASR requires a limited license for ASR testing before a permanent ASR permit may be obtained (690-350-0010(2) OAR). The limited license may cover ASR testing for a single well or same-aquifer wells in a wellfield. The injection source water for ASR is required to comply with drinking water standards, treatment requirements, and performance standards established by the state Health Department or maximum measurable levels established by the Environmental Quality Commission, whichever are more stringent. Conditions are placed in the limited license or permit to minimize, to the extent technically feasible, practical, and cost-effective, the concentration of constituents in the injection source water that are not naturally present in the aquifer. No license or permit may establish concentration limits for water to be injected for ASR in excess of standards established by the Health Department or the Environmental Quality Commission (690-350-0010(6)(a)-(c) OAR). If the injection source water contains regulated constituents that are detected at greater than 50 percent of the established levels, the ASR limited license or permit may require the permittee to employ technically feasible, practical, and cost-effective methods to minimize concentrations of such constituents in the injection source water. Constituents that are associated with disinfection of the water may be injected into the aquifer up to the standards established in the state. Further restrictions may be placed on certain constituents if the Water Resources Department finds that they will interfere with or pose a threat to the maintenance of the water resources of the state for present or future beneficial uses.

An application for a limited license must specify the proposed source for injection water, maximum diversion rate, maximum injection rate at each well, maximum storage volume, maximum storage duration, and maximum withdrawal rate at each well. It must specify the proposed beneficial use or the intended disposal method for the recovered water. Access to water for injection must be evidenced by a completed water availability statement from the local watermaster, results from the DEQ's water availability model, or citation of an existing water right. If the applicant is not the holder of the water right for the proposed ASR testing, permission for use must be obtained. Applicants are encouraged to protect their ground water supply through the development of a Wellhead Protection plan (690-350-0020 OAR).

The proposed ASR testing program must include water quality sampling, quality assurance/quality control, and water level monitoring. The proposed system design must include well construction information for any injection wells. Detailed preliminary hydrogeologic information must be provided. Detailed information must be provided on the quality of the source water and the quality of the receiving aquifer water. Application for a permanent ASR permit requires submission of detailed information on all of the topics included in the application for a limited license (690-350-0030 OAR). The Water Resources Department consults with the Health Department and DEQ about the completeness of the applications for a limited license or permit.

An application for a ground water recharge permit must include all of the information required under OAR 690-310-0040. Use of artificially recharged waters requires a secondary ground water permit specifying the maximum diversion rate and volume of withdrawals and allowable uses of stored recharged water (690-350-0130 OAR).

Siting and Construction Requirements

The permit application must include the proposed system design, including well construction information, the wellhead assembly, piping system for injection and recovery, and other conceptual design components of the system. A licensed professional must develop this information (690-350-0030(4)(b)(B) OAR).

Operating Requirements

Not specified by statute or regulations.

Monitoring Requirements

Not specified by statute or regulations.

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

The state UIC requirements provide that upon discontinuance of use or abandonment a waste disposal well is required to be rendered completely inoperable by plugging and sealing the hole. All portions of the well which are surrounded by "solid wall" formation must be plugged and filled with cement grout or concrete. The top portion of the well must be effectively sealed with cement grout or concrete to a depth of at least 18 feet below the surface of the ground, or if this method of sealing is not effective by a manner approved by the DEQ. The Water Resources Department's requirements for ASR and aquifer recharge wells do not address plugging or abandonment.

South Carolina

South Carolina is a UIC Primacy State for Class V wells and the UIC program is implemented by the Department of Health and Environmental Control (DHEC). The UIC regulations, found in Chapter 61 of the State Code of Regulations, divide Class V wells into two groups, with aquifer recharge wells found in group A.

Permitting

Class V.A. wells, which include recharge wells used to replenish the water in an aquifer, are prohibited except as authorized by permit (R61-87.10.E.(1)(b) and (2)). The permit application must include a description of the activities to be conducted, the name, address, and location of the facility, the names and other information pertaining to the owner and operator, a description of the business, and proposed operating data, including average and maximum daily rate and volume of fluid to be injected, average and maximum injection pressure, and source and an analysis of the chemical, physical, biological, and radiological characteristics of the injected fluid; and drawings of the surface and subsurface construction of the well (R61-87.13.G(2)). The movement of fluids containing wastes or contaminants into USDWs as a result of injection is prohibited if the waste or contaminant may cause a violation of any drinking water standard or otherwise adversely affect the health of persons (R61-87.5).

Siting and Construction Requirements

Siting and operating criteria and standards for Class V.A wells require logs and tests, which will be specified by DHEC in the permit, to identify and describe USDWs and the injection formation (R61-87.14).

Injection may not commence until construction is complete, the permittee has submitted notice of completion to DHEC, and DHEC has inspected the well and found it in compliance (R61-87.13U).

Operating Requirements

Operating requirements for Class V.A wells are the same as those for Class II and III wells (R61-87.14). DHEC will establish maximum injection volumes and pressures and such other permit conditions as necessary to assure that fractures are not initiated in the confining zone adjacent to a USDW and to assure compliance with operating requirements (R61-87.13V).

Monitoring Requirements

Monitoring requirements will be specified in the permit. Monitoring requirements for Class V.A wells are the same as those for Class III wells, and may include monitoring wells (R61-87.14.G). Quarterly reporting of monitoring results is required to DHEC (R61-87.14.I(1)).

Mechanical Integrity Testing

Prior to granting approval for operation, DHEC will require a satisfactory demonstration of mechanical integrity. Tests will be performed at least every 5 years (R61-87.14.G).

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

A plugging and abandonment plan must be prepared and approved by DHEC (R61-87.15).

Texas

Texas is a UIC Primacy State for Class V wells. The Injection Well Act (Chapter 27 of the Texas Water Code) and Title 3 of the Natural Resources Code provide statutory authority for the UIC program. Regulations establishing the UIC program are found in Title 30, Chapter 331 of the Texas Administrative Code (TAC). Aquifer recharge wells used to replenish water in an aquifer are specifically defined as Class V wells (331.11 (a)(4)(F) TAC). Aquifer storage wells used for the injection of water for storage and subsequent retrieval for beneficial use are also specifically defined as Class V wells (331.11 (a)(4)(K) TAC).

Permitting

Underground injection is prohibited, unless authorized by permit or rule (331.7 TAC). By rule, injection into a Class V well is authorized, although the Texas Natural Resources Control Commission (TNRCC) may require the owner or operator of a well authorized by rule to apply for and obtain an injection well permit (331.9 TAC). No permit or authorization by rule is allowed where an injection well causes or allows the movement of fluid that would result in the pollution of a USDW. A permit or authorization by rule must include terms and conditions reasonably necessary to protect fresh water from pollution (331.5 TAC).

Siting and Construction Requirements

All Class V wells are required to be completed in accordance with explicit specifications in the rules, unless otherwise authorized by the TNRCC. These specifications are:

- A form provided either by the Water Well Drillers Board or the TNRCC must be completed.
- The annular space between the borehole and the casing must be filled from ground level to a depth of not less than 10 feet below the land surface or well head with cement slurry. Special requirements are imposed in areas of shallow unconfined ground water aquifers and in areas of confined ground water aquifers with artesian head.

C In all wells where plastic casing is used, a concrete slab or sealing block must be placed above the cement slurry around the well at the ground surface; and the rules include additional specifications concerning the slab.

C In wells where steel casing is used, a slab or block will be required above the cement slurry, except when a pitless adaptor is used, and the rules contain additional requirements concerning the adaptor.

C All wells must be completed so that aquifers or zones containing waters that differ significantly in chemical quality are not allowed to commingle through the borehole-casing annulus or the gravel pack and cause degradation of any aquifer zone.

C The well casing must be capped or completed in a manner that will prevent pollutants from entering the well.

C When undesirable water is encountered in a Class V well, the undesirable water must be sealed off and confined to the zone(s) of origin (331.132 TAC).

Operating Requirements

None specified. Chapter 331, Subpart H, "Standards for Class V Wells" addresses only construction and closure standards (331.131 to 331.133 TAC).

Monitoring Requirements

Not specified by statute or regulations.

Mechanical Integrity Testing

Injection may be prohibited for Class V wells that lack mechanical integrity. The TNRCC may require a demonstration of mechanical integrity at any time if there is reason to believe mechanical integrity is lacking. The TNRCC may allow plugging of the well or require the permittee to perform additional construction, operation, monitoring, reporting, and corrective actions which are necessary to prevent the movement of fluid into or between USDWs caused by the lack of mechanical integrity. Injection may resume on written notification from the TNRCC that mechanical integrity has been demonstrated (331.4 TAC).

Financial Assurance

Chapter 27 of the Texas Water Code, "Injection Wells," enacts financial responsibility requirements for persons to whom an injection well permit is issued. A performance bond or other form of financial security may be required to ensure that an abandoned well is properly plugged (§ 27.073). Detailed financial responsibility requirements also are contained in Chapter 331, Subchapter I of the state's UIC regulations (331.141 to 331.144 TAC). A permittee is required to secure and maintain a performance bond or other equivalent form of financial assurance or guarantee to ensure the closing, plugging, abandonment, and post-closure care of the injection operation. However, the requirement, unless incorporated into a permit, applies specifically only to Class I and Class III wells (331.142 TAC).

Plugging and Abandonment

Plugging and abandonment of a well authorized by rule is required to be accomplished in accordance with §331.46 TAC (331.9 TAC). In addition, closure standards specific to Class V wells provide that closure is to be accomplished by removing all of the removable casing and filling the entire well with cement to land surface. Alternatively, if the use of the well is to be permanently discontinued, and if the well does not contain "undesirable" water, the well may be filled with fine sand, clay, or heavy mud followed by a cement plug extending from the land surface to a depth of not less than 10 feet. If the use of a well that does contain undesirable water
is to be permanently discontinued, either the zone(s) containing undesirable water or the fresh water zone(s) must be isolated with cement plugs and the remainder of the wellbore filled with sand, clay, or heavy mud to form a base for a cement plug extending from the land surface to a depth of not less than 10 feet (331.133 TAC).

Washington

Washington is a UIC Primacy State for Class V wells. Chapter 173-218 of the Washington Administrative Code (WAC) establishes the state's UIC program. Under this program, the policy of the Department of Ecology is to maintain the highest possible standards to prevent the injection of fluids that may endanger ground waters which are available for beneficial uses or which may contain fewer than 10,000 mg/l total dissolved solids. Consistent with that policy, all new Class V injection wells that inject industrial, municipal, or commercial waste fluids into or above a USDW are prohibited (172-218-090(1) WAC). Existing wells must obtain a permit to operate.

In addition, the state has enacted standards for direct ground water recharge projects using reclaimed water (Water Reclamation and Reuse Standards, Section 3). These rules primarily address the standards and treatment requirements for the reclaimed water, when injected into potable ground water and when injected into nonpotable ground water. For potable ground water, the requirements also include construction standards for withdrawal facilities, requiring them to comply with 173-136 and 173-150 WAC. The rules include reclaimed water sampling and analysis and monitoring requirements, operational requirements for the reclamation plant, disinfection requirements, mandatory retention time prior to withdrawal, and ground water monitoring requirements (Articles 3 to 6). However, these rules do not address requirements for injection and/or withdrawal wells, except for the requirement pertaining to wells withdrawing water from potable aquifers.

Permitting

A permit must specify conditions necessary to prevent and control injection of fluids into the waters of the state, including all known, available, and reasonable methods of prevention, control, and treatment; applicable requirements in 40 CFR Parts 124, 144, 146; and any conditions necessary to preserve and protect USDWs. Any injection well that causes or allows the movement of fluid into a USDW that may result in a violation of any primary drinking water standard under 40 CFR Part 141 or that may otherwise adversely affect the beneficial use of a USDW is prohibited (173-218-100 WAC).

Siting and Construction Requirements

The state has promulgated minimum standards for construction and maintenance of wells (173-160-010 through -560 WAC). However, injection wells regulated under Chapter 173-218 are specifically exempted from these constructions standards (173-160-010(3)(e) WAC).

Operating Requirements

The water quality standards for ground waters establish an antidegradation policy. The injectate must meet the state's ground water standards at the point of compliance (173-200-030 WAC).

Monitoring Requirements

Not specified by statute or regulations.

Mechanical Integrity Testing

Not specified by statute or regulations.

Financial Assurance

Not specified by statute or regulations.

Plugging and Abandonment

All wells not in use must be securely capped so that no contamination can enter the well (173-160-085 WAC).

REFERENCES

Amans, L.C. and J. McLeod. 1988. Kerrville, Texas--A Case Study for Aquifer Storage Recovery. In International Symposium on Class V Injection Well Technology, held in Las Vegas, Nevada. Underground Injection Practices Council, 203-221. September 13-15, 1988.

Antelope Valley Board of Trade. 1997. Aquifer Storage and Recovery Testing Continues. Antelope Valley Business News. Available: http://www.avbot.org/avdn/mar97/aquifer.html.

Atkinson, S.F., G.D. Miller, and D.S. Curry. 1986. Salt-water Intrusion, Status and Potential in the Contiguous United States. Chelsea, Michigan: Lewis Publishers.

Bouwer, H., R.D.G. Pyne, and J.A. Goodrich. 1990. Recharging Groundwater. Civil Engineering. American Society of Civil Engineers, 1:6: 63-66.

Bloetscher, F. 1999. Comments on the May 17, 1999 Draft of The Class V Underground Injection Control Study: Salt Water Intrusion Barrier Wells Information Summary. Florida Governmental Utility Authority. June 16, 1999.

Breault, R.L. 1997. Project Management During Design and Construction of an Aquifer Storage & Recovery Wellfield. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, Long Beach, California. Herdon, Virginia: American Water Resources Association, 357-363. October 19-23, 1997.

Bruington, A.E. 1968. The Amelioration of Prevention of Salt-Water Intrusion in Aquifers-Experience in Los Angeles County, California. Salt-water Encroachment into Aquifers: Proceedings of the Limited Professional Symposium, Louisiana State University, Baton Rouge, Louisiana, May 4-5, 1967. Baton Rouge: Louisiana Water Resources Research Institute Bulletin 3. October 1968.

Calleguas Municipal Water District. Las Posas Basin Aquifer Storage and Recovery Project. Available: http://www.calleguas.com/lpb.html.

Castro, J.E. and L.R. Gardner. 1997. "A Geochemical Model for the Aquifer Storage and Recovery Project at Myrtle Beach, SC." Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, held in Long Beach, California, October 19-23, 1997. American Water Resources Association. pp 201-210.

Centennial Water and Sanitation District. 1998. Water Analysis Report of Water Samples Collected at Location K01: Well A-6 Recharge on February 11, 1998, April 23, 1998, and July 28, 1998. September 30, 1998.

City of Oxnard. 1996. *Annual Water Quality Report: Water Quality Program.* Oxnard, California.

City of Salem. 1999. Letter from Mr. Paul Eckley, Chief Utilities Engineer, City of Salem, to Mr. Donn Miller, Hydrogeologist, Oregon Water Resources Department re 1998 Annual Report for ASR Limited License #001. February 11, 1999.

Crook, J., T. Asano, and M. Nellor. 1991. Groundwater Recharge with Reclaimed Water in California. Municipal Wastewater Reuse: Selected Readings on Water Reuse. 67-74. Washington, D.C.: U.S. Environmental Protection Agency. EPA 430/09-91-022.

Culp, R.L.. 1981. Treatment Processes to Meet Water Reuse Requirements. Water Engineering and Management 28:4: 72-76.

Deuerling, R. 1997. Florida Department of Environmental Regulations. Memorandum to Anhar Karimjee, Office of Water, U.S. Environmental Protection Agency, Tallahassee, FL. November 14, 1997.

Deuerling, Rich. 1999. Comments on the April 30, 1999 Draft of the Class V Underground Injection Control Study: Aquifer Recharge Well Information Summary. State of Florida. June/July 1999.

Dickenson, J.M. 1997. ASR and Ground water Basin Management. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery. Long Beach, California. Herndon, Virginia: American Water Resources Association, 155-162. October 19-23, 1997.

Driscoll, F. G. 1986. Groundwater and Wells (Second Edition). Johnson Division. St. Paul, Minnesota.

Eckley, Paul. 1999. Comments on the May 14, 1999 Draft of the Class V Underground Injection Control Study: Aquifer Storage and Recovery Well Information Summary. Oregon Public Works Department. City of Salem, Oregon. June 9, 1999.

Fairchild, D.M. 1985. Multi-Purpose Approach to Ground Water Management. Proceedings of the Association of Ground Water Scientists and Engineers, Southern Regional Water Conference, San Antonio, Texas. Worthington, OH: National Water Well Association. September 18-19, 1985.

Florida Department of Environmental Protection (FDEP). 1998. Map titled Aquifer Storage and Recovery Facilities. December 1998. Table titled Aquifer Storage and Recovery Facilities in Florida. Updated: December 7, 1998.

Freeze, R. A. and J. A. Cherrry. 1979. Groundwater. Printice Hall, Inc. Englewoods Cliffs, New Jersey.

Griffis, C.L. 1976. Artificial Recharge in the Grand Prairie, Arkansas. Bulletin 810, Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas. August, 1976.

Hamlin, S.M. 1987. Hydraulic/Chemical Changes During Ground-Water Recharge by Injection. Groundwater 25:3: 267-274.

Horvath, Lloyd. 1997. ViroGroup, Inc. Memorandum to Kim Clemente, The Cadmus Group, Inc. List of ASR projects that ViroGroup has undertaken, 1997. Cape Coral, FL.

Horvath, L.E., M.S. Pearce, and H.J. Losch. 1997. Using Aquifer Storage and Recovery to Meet Seasonally Fluctuating Water Demand and Water Availability Cycles at Marco Island, Florida. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, Long Beach, California. Herndon, Virginia: American Water Resources Association, 61-70. October 19-23, 1997.

Kazman, R.G. 1967. Perspectives in Artificial Recharge. American Water Resources Association, Proceedings Series #4, pp. 187-192.

Lacombe, P.J. 1997. Artificial Recharge of Ground Water by Well Injection for Storage and Recovery, Cape May County, New Jersey, 1958-92. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, Long Beach, California. Herndon, Virginia: American Water Resources Association, 33-41. October 19-23, 1997.

Lichtler, W.F., D. Stannard, and E. Kourna. 1980. “Investigation of Artificial Recharge of Aquifers in Nebraska.” Water-Resources Investigations: 80-93. U.S. Geological Survey. Reston, VA.

Lucas, M. and K. McGill. 1997. “Aquifer Treatment Methods for Preventing Iron Concentrations in the Recovered Water From Aquifer Storage and Recovery Wells Installed in Clayey Sand Aquifers of the Atlantic Coastal Plain.” Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery. Held in Long Beach, California October 19-23, 1997. American Water Resources Association. pp 449-458.

McNeal, M.B., A.E. Fox, N.J. LoPriesti, and K.E. Coates. 1997. Seasonal Storage of High Quality Reclaimed Water. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, Long Beach, California. Herndon, Virginia: American Water Resources Association, 427-435. October 19-23, 1997.

Memphis Light, Gas, and Water Division, 1997. Letter from Mr. Charles Pickel, Manager, Gas and Water Engineering, to Ms. Robin Bell, Manager, Underground Injection Program, Tennessee Department of Environment and Conservation, Division of Water Supply, March 5, 1997.

Miller, T.J. and R.R. Beavers. 1997. ASR Using a Deep Midwestern Aquifer: Des Moines (Iowa) Water Works ASR Demonstration Project. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, Long Beach, California. Herndon, Virginia: American Water Resources Association, 89-98. October 19-23, 1997.

North Carolina Division of Water Resources. 1996. Strategic Management Implications of Water Reclamation and Reuse on Water Resources.

O'Hare, M.P., D.M. Fairchild, P.A. Hajali, and L.W. Canter. 1986. Artificial Recharge of Groundwater. Chelsea, MI: Lewis Publishers.

Olson, Gregg. 1999. Comments on the April 30, 1999 Draft of the Class V Underground Injection Control Study: Aquifer Recharge Well Information Summary. USEPA Region 9. June 23, 1999.

Palmer, R., D. Wendell, A. Hutchinson, and T. Foreman. 1997. "Optimization of ASR Operations in a Nitrate and PCE Contaminated Aquifer." Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, held in Long Beach California, October 19-23, 1997. American Water Resources Association. pp 3-11.

Pitt, W.A.J. and S. Magenheimer. 1997. ASR Technology: Avoidance and Solutions to Aquifer Clogging Problems. Proceedings of AWRA Symposium, Conjunctive Use of Water Resources: Aquifer Storage and Recovery, Long Beach, California. Herndon, Virginia: American Water Resources Association, 251-260. October 19-23, 1997.

Powers, J. Patrick. 1992. Construction Dewatering: New Methods and Applications. Second Edition. John Wiley & Sons, Inc.

Priest, Barbara. 1999. UIC Program Coordinator, Water Quality Division, Oregon Department of Environmental Quality. Telephone Conversation with Maribelle Rodríguez, ICF Consulting. September 9 and 14, 1999.

Pyne, R.D.G. 1995. Ground water Recharge and Wells: A Guide to Aquifer Storage Recovery. Boca Raton, Florida: Lewis Publishers.

Schaefer, V.R., DeBoer, D.E., and Emmons, P.J. 1994. Huron Project of the High Plains States Demonstration Program. Artificial Recharge of Ground Water, II: Proceedings of the Second International Symposium on Artificial Recharge of Ground Water. American Society of Civil Engineers.

Shea-Albin, V. 1997. "Summary of info from the Report to Congress on the High Plains Aquifer Project (prepared by USEPA to be part of the preamble)." USEPA Region 8. Denver, CO. Correspondence to Anhar Karimjee, Office of Water, U.S. Environmental Protection Agency. October 31, 1997.

Singer, P.C., et al. Examining the Impact of Aquifer Storage and Recovery on DBPs. Journal of the American Water Works Association, 85-94. November 1993.

Sniegocki, R.T. and Brown, R.F. 1970. Clogging in Recharge Wells, Causes and Cures. Proceedings Artificial Ground Water Recharge Conference. Water Res. Assn. England. 337.

South Dakota State University. 1993. Memorandum Rule Authorization for Huron Project of the High Plains States Groundwater Demonstration Program. Addressed to Mr Arnold Boettcher, USEPA. March 26, 1993.

Southwest Florida Water Management District. The Peace River Option: A Balance Between Nature and People. Issue Paper No. 8. Available: http://www.dep.state.fl.us/swfwmd/SWFI008.html.

Terada, Calvin. 1999. Final Modified Inventories for Class V UIC Study-- Idaho, Oregon, and Washington. E-mail from USEPA Region 10 to Anhal Karimjee, USEPA Office of Ground Water and Drinking Water. February 24, 1999.

Tennessee Department of Environment and Conservation (TDEC). 1996a. Letter from Mr. Justin Wilson, Commissioner, Tennessee Department of Environment and Conservation, Division of Water Supply, to Mr. Charles Pickel, Manager. Gas and Water Engineering, Memphis Light, Gas, and Water Division. Re: UIC Class V Permit, MLGW, Shelby County, May 30, 1996.

Tennessee Department of Environment and Conservation (TDEC). 1996b. Underground Injection Control Permit - Authorization to Operate a Class V Injection Well, issued to Memphis Light, Gas, and Water Division, May 30, 1996.

Tennessee Department of Environment and Conservation. 1996c. Memorandum from Ms. Robin Bell, Manager, Underground Injection Program, Tennessee Department of Environment and Conservation, Division of Water Supply, to Mr. Justin Wilson, Commissioner, Tennessee Department of Environment and Conservation, Division of Water Supply: Re: Request review and approval to issue Class V Underground Injection Control (UIC) Permit, May 8, 1996.

Texas Department of Water Resources. 1984. Underground Injection Operations in Texas: A Classification and Assessment of Underground Injection Activities. Chapter 8: Artificial Recharge Wells. December 1984.

Todd, D. K. 1980. Groundwater Hydrology (Second Edition). John Wiley & Sons.

U.S. Bureau of Reclamation. No date #1. High Plains States Groundwater Demonstration Program, Interim Report.

U.S. Bureau of Reclamation. No date #2. Huron Project of the High Plains States Groundwater Demonstration Program Progress Report for the Period November 1, 1991 to May 31, 1992.

U.S. Bureau of Reclamation. 1996. Hueco Bolson Recharge Demonstration Study Summary. April 1996.

U.S. Department of the Interior. 1996. A Comprehensive Plan for the Restoration of the Everglades. January 19, 1996.

USEPA. 1997. Source Water Assessment and Programs Guidance. Office of Water. Washington, D.C. EPA 816-R-97-009. August 1997.

U.S. Geological Survey. Water-Quality Effects of Aquifer Storage and Recharge of the Equus Beds at the Ground-Water Recharge Demonstration Project Site Near Wichita, Kansas. Project Number KS194. Available: http://www-ks.cr.usgs.gov/Kansas/studies/project.html.

Walker, Charles W. 1999. Comments on the May 14, 1999 Draft of the Class V Underground Injection Control Study: Aquifer Storage and Recovery Well Information Summary. Missimer International, Inc. June 17, 1999.

Warner, D. L. 1965. Deep well injection of liquid waste. Environmental Health Series, Water Supply and Pollution Control, No. 999-WP-21. U.S. Department of Health, Education and Welfare. Cincinnati, Ohio.

Wilson, Karen. 1999. Comments on the May 14, 1999 Draft of the Class V Underground Injection Control Study: Aquifer Storage and Recovery Well Information Summary. USEPA Region 4. June/July, 1999.